

Fingerprints: An Overview



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Skin on the finger

finger



arm



- The skin on the finger contains friction ridges, has no hair, has no oil glands, and has lots of sweat pores
- The pattern of ridges is believed to be **unique & persistent**, thus useful for person identification
- Touching an object will leave **latent print** on it, thus useful for solving crime

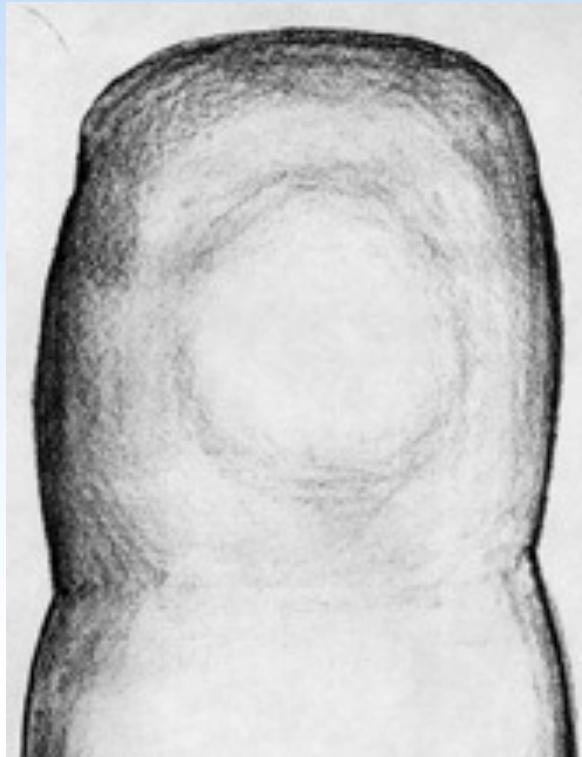
Fingerprints



- **Description:** graphical flow like ridges present in human fingers
- **Formation:** during embryonic development
- **Permanence:** minute details are believed to not change over time
- **Uniqueness:** believed to be unique to each finger
- **History:** used in forensics and has been extensively studied

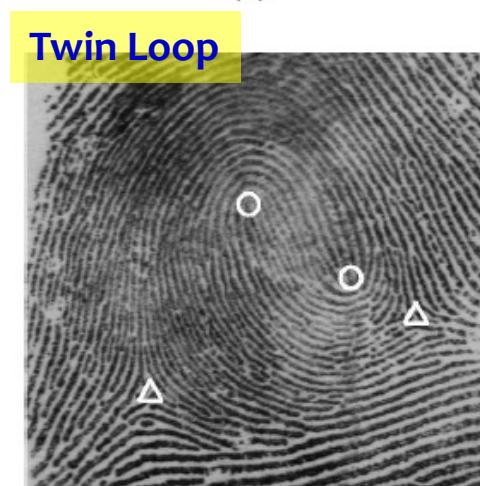
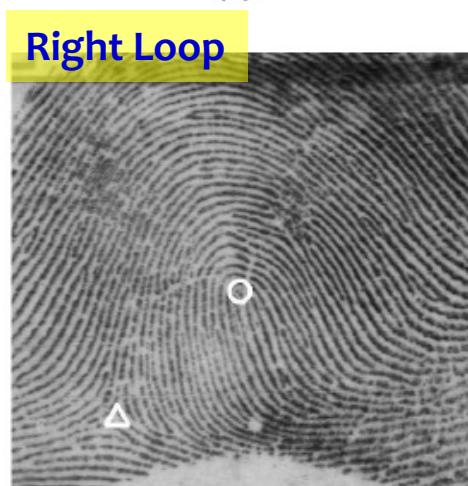
Fingerprint Formation

- Ridge formation starts at 1 or 2 focal points and spreads over the fingertip
- Localized ridge units merge to form ridges at ~10.5 weeks estimated gestational age



Fingerprint Classification

- Assign fingerprints into one of pre-specified types



Fingerprint recognition

- Determine if two fingerprint images originate from the same finger or not
- Use principles of object sensing, image processing, computer vision, and pattern recognition to automate the process



3 representative applications



FBI IAFIS
Law enforcement
1-to-N



DHS OBIM
Border control
1-to-N & 1-to-1



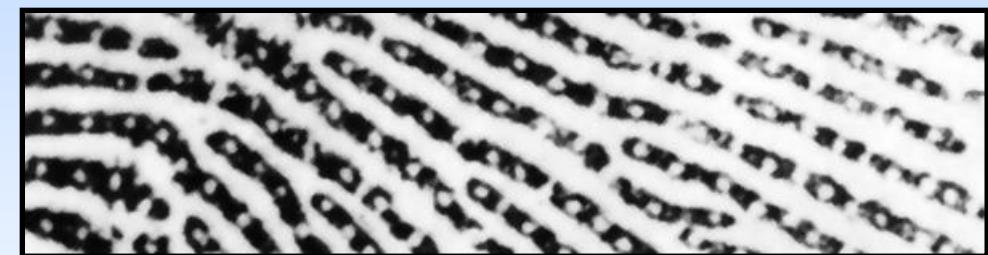
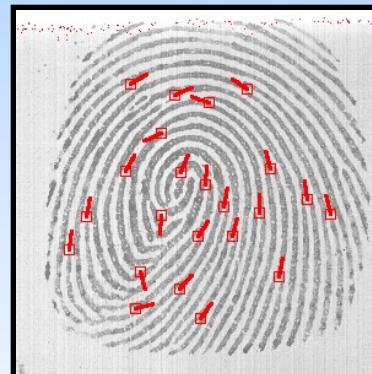
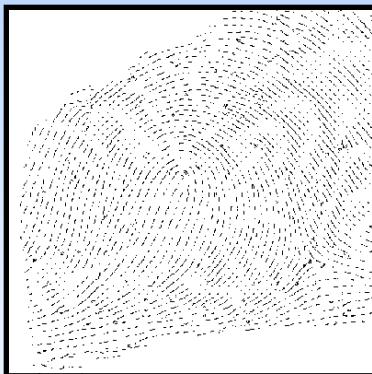
iPhone
Access control
1-to-1

Image Resolution

Level I
(<250 dpi)

Level II
(250 – 512 dpi)

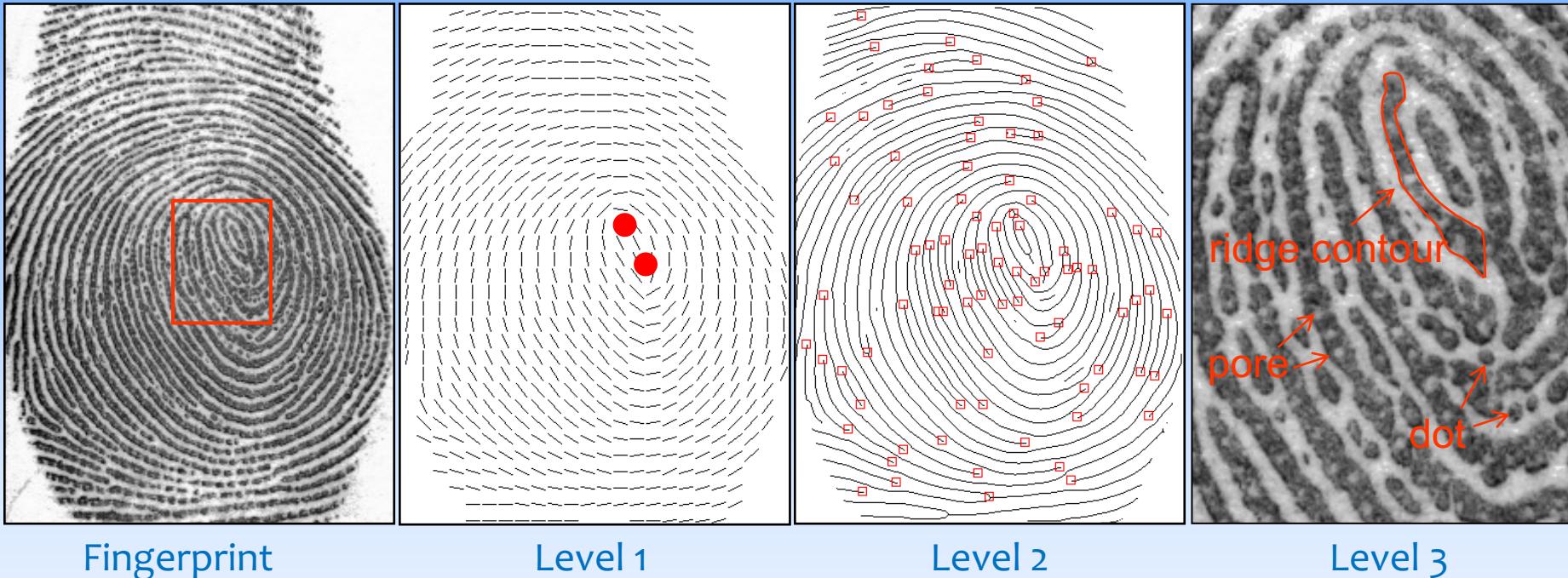
Level III



Increasing Resolution

- Increasing the resolution of the scanner reveals biometric details that can enhance the “uniqueness” of the trait
- However, this may lead to an increase in “noise”

Fingerprint features

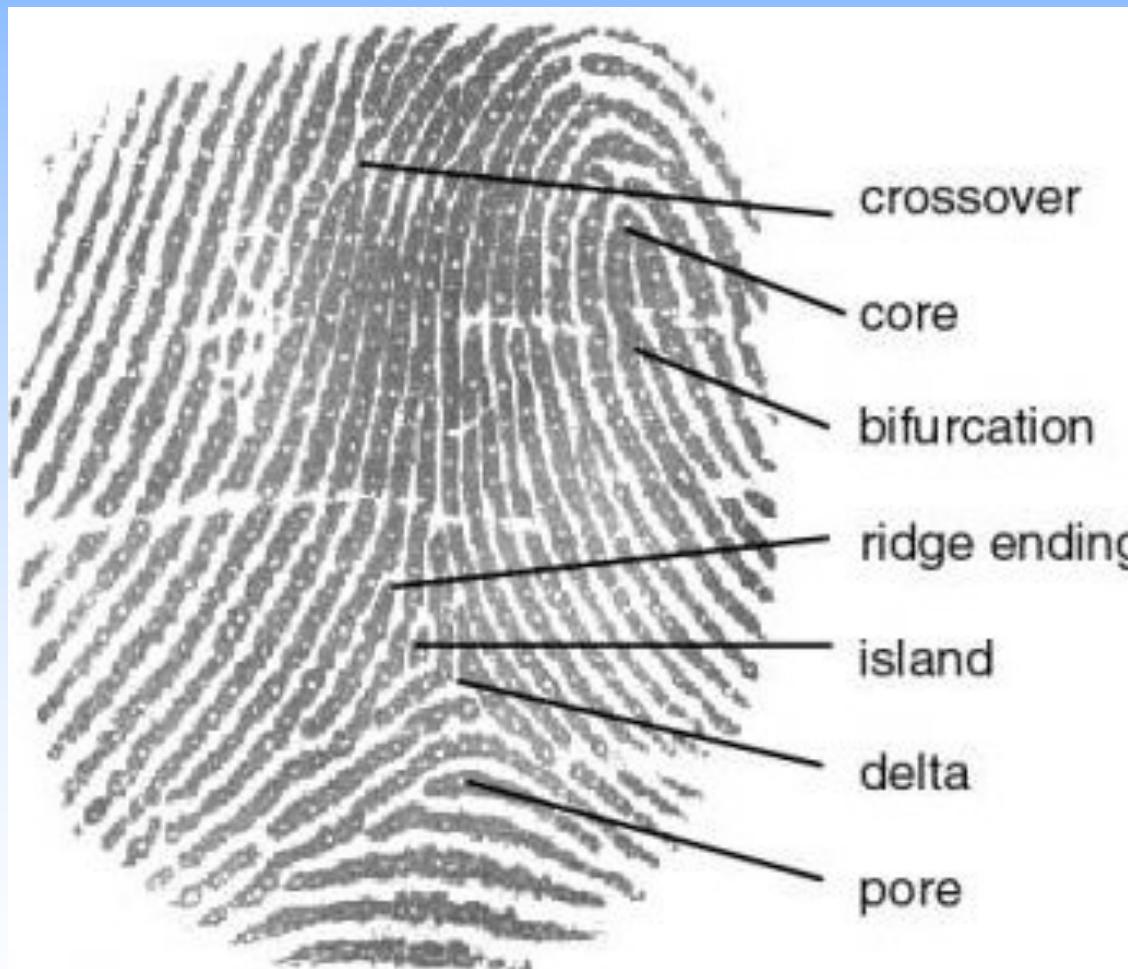


A fingerprint can be described at **3 levels** from coarse to fine. Coarse level representation can be derived from finer level representations.

- **Level 1:** ridge orientation and frequency → singular points
- **Level 2:** ridge skeletons → minutiae points
- **Level 3:** outer and inner contours of ridges

Fingerprint features at 3 different levels

Fingerprints



Fingerprint Acquisition Methodology



Flat/Dab Fingerprint

(One-touch print from a single-finger livescan device)



Slap Fingerprint

(4-finger simultaneous impression from livescan devices or scanned from paper FP cards)



Rolled Fingerprint

(Image collected by rolling the finger across the livescan platen or paper from nail to nail)

Inking method

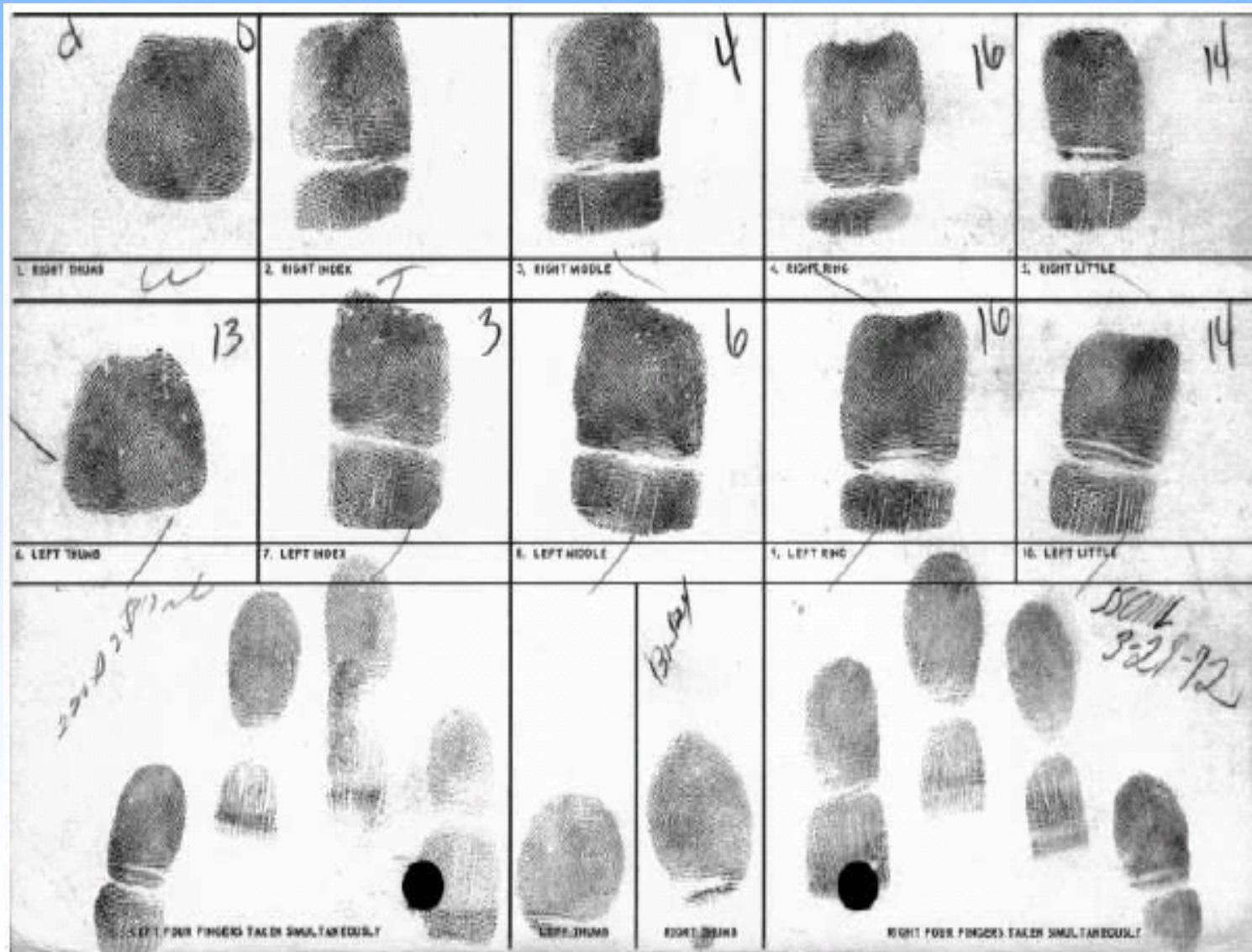
rolled fingerprints



plain fingerprints

- **Rolled** fingerprints are larger in size, but distortion is large due to rolling.
- **Plain** fingerprints are smaller in size, but distortion is smaller.
- Plain fingerprints are also used to ensure correct order of rolled fingerprints.
- **Both** rolled and plain fingerprints are captured in an attended mode, so quality is good and contain rich information.
- They are also called exemplar fingerprints.

Ink Database (Rolled & Slap)



Recording latent prints

- Recording latent prints (latent development) requires diverse techniques, depending on residue type, surface type, age...
- Powder dusting is one of the oldest and most common techniques.



1. Dust by powder



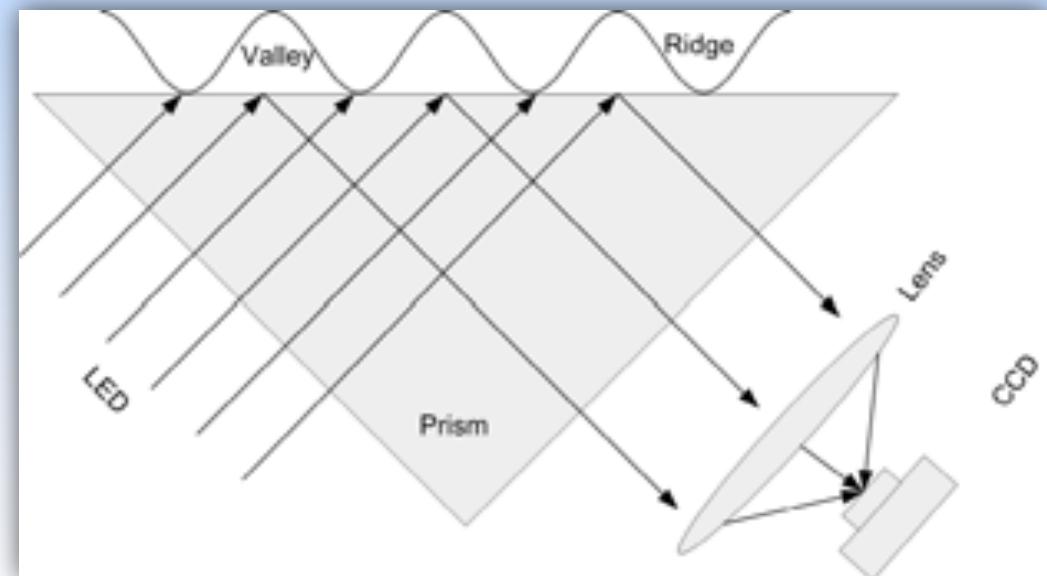
2. Take photograph



3. Lift by tape

Online sensing techniques

- Many online fingerprint sensing techniques:
 - Optical Frustrated Total Internal Reflection (FTIR)
 - Capacitive
 - Ultrasonic
 - Thermal
 - Direct imaging



Online sensing



Press the finger



Roll the finger



Sweep finger



Press the hand

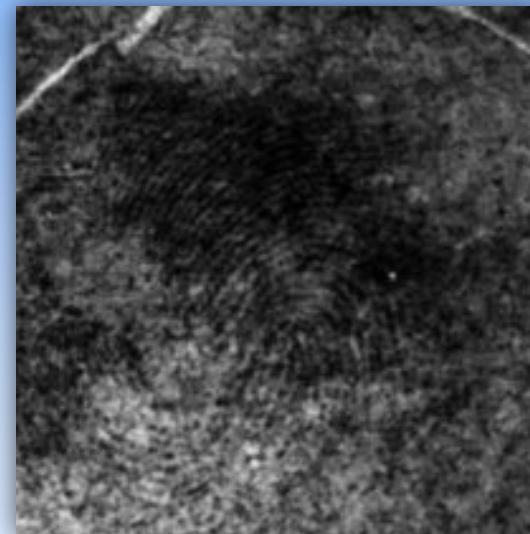


Sweep hand

Images of different sensing methods



Inking



Latent

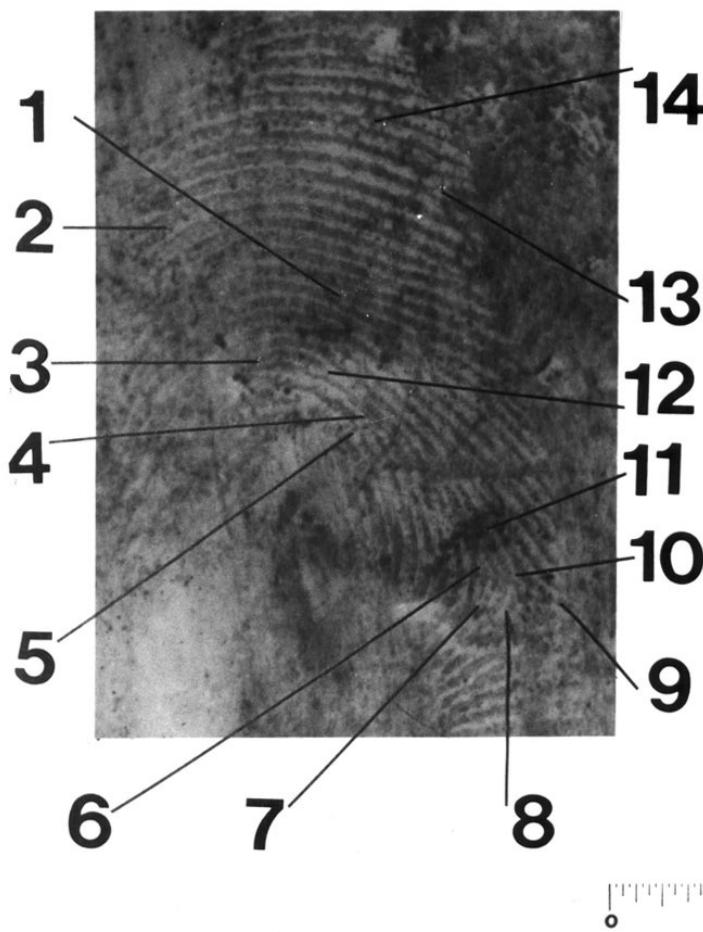


FTIR

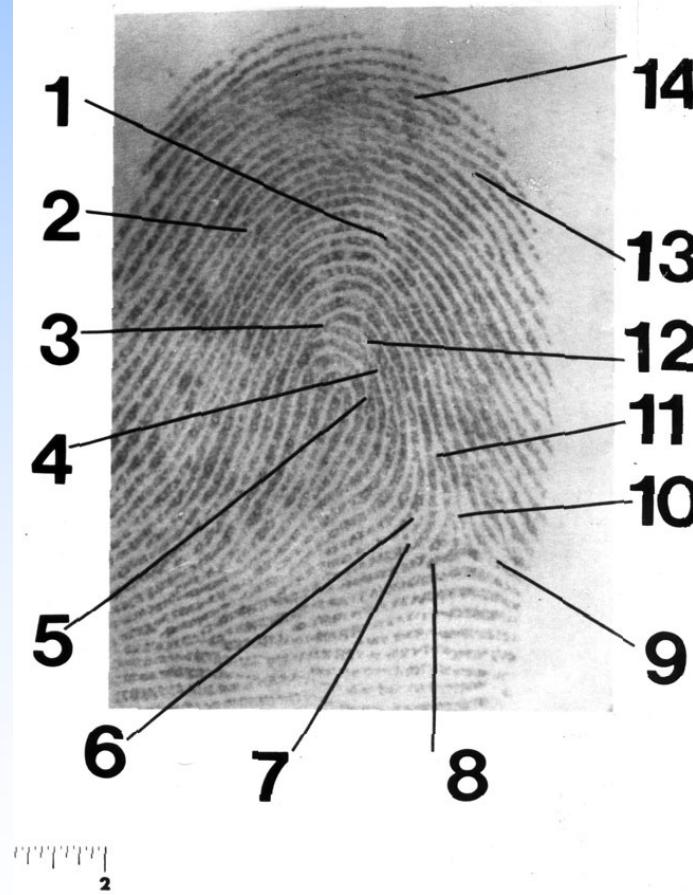
Compared to inking and FTIR fingerprints, quality of latent fingerprint is much lower

Minutiae-based Representation

LATENT FINGERPRINT

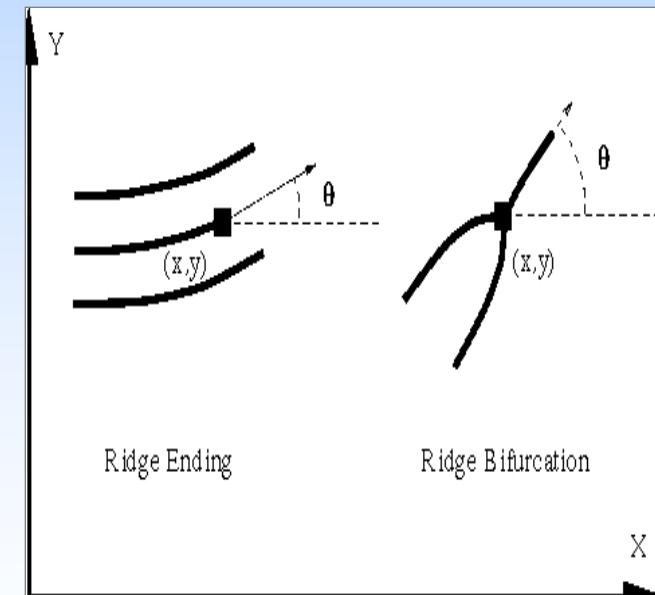
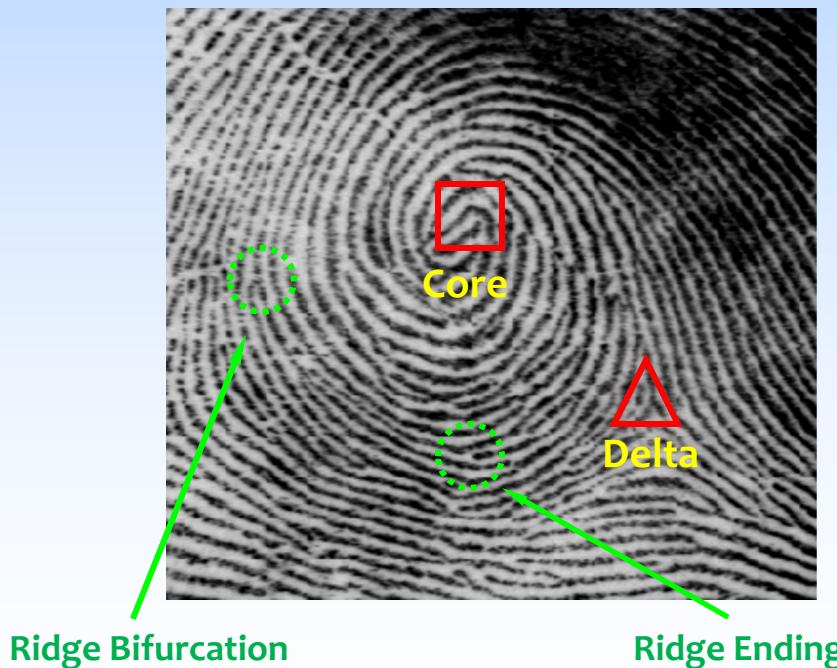


INKED FINGERPRINT

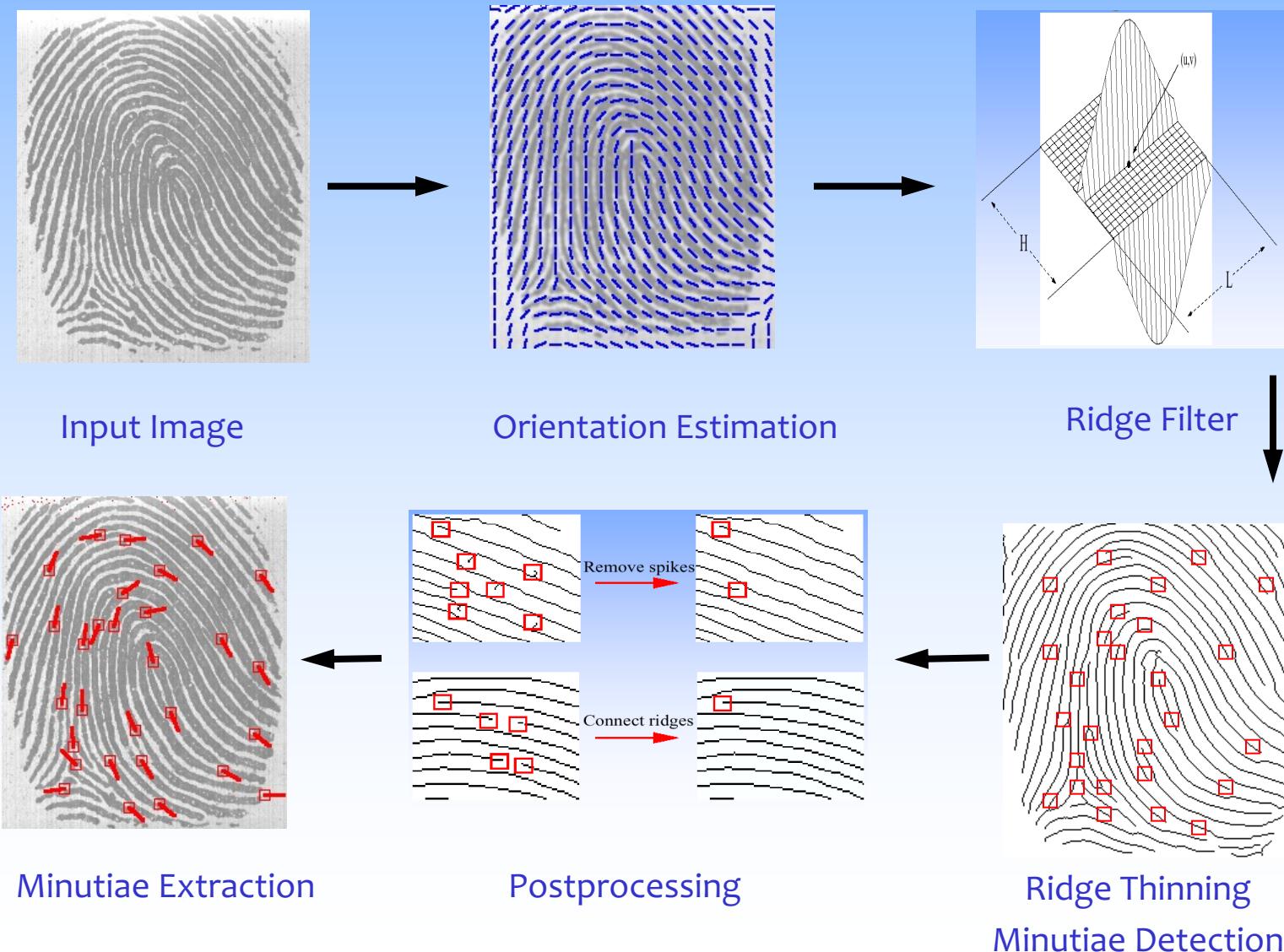


Fingerprint Representation

- Local ridge characteristics (**minutiae**): ridge ending and ridge bifurcation
- Singular points: Discontinuities in ridge orientation



Minutiae Extraction



Rotation and Translation



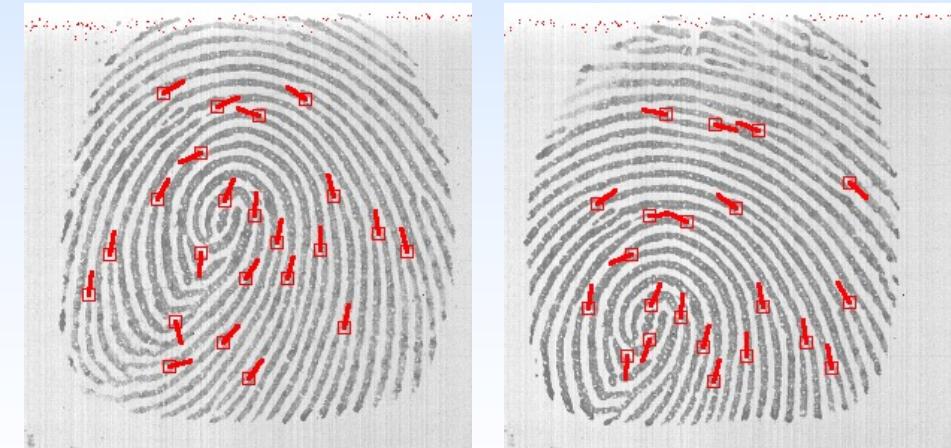
Non-linear Deformation



Intra-class Variations

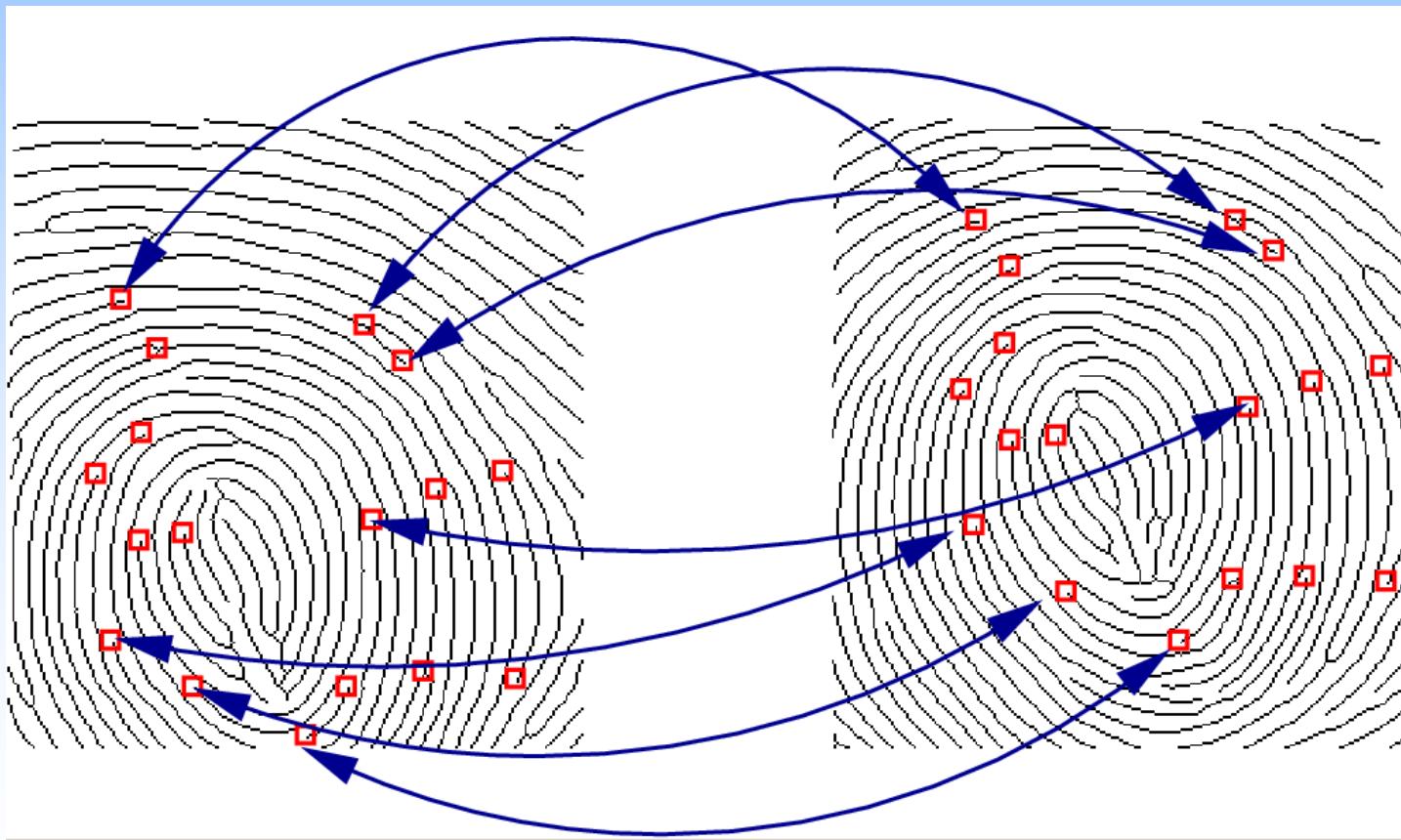


Three impressions of a user' s finger (optical)



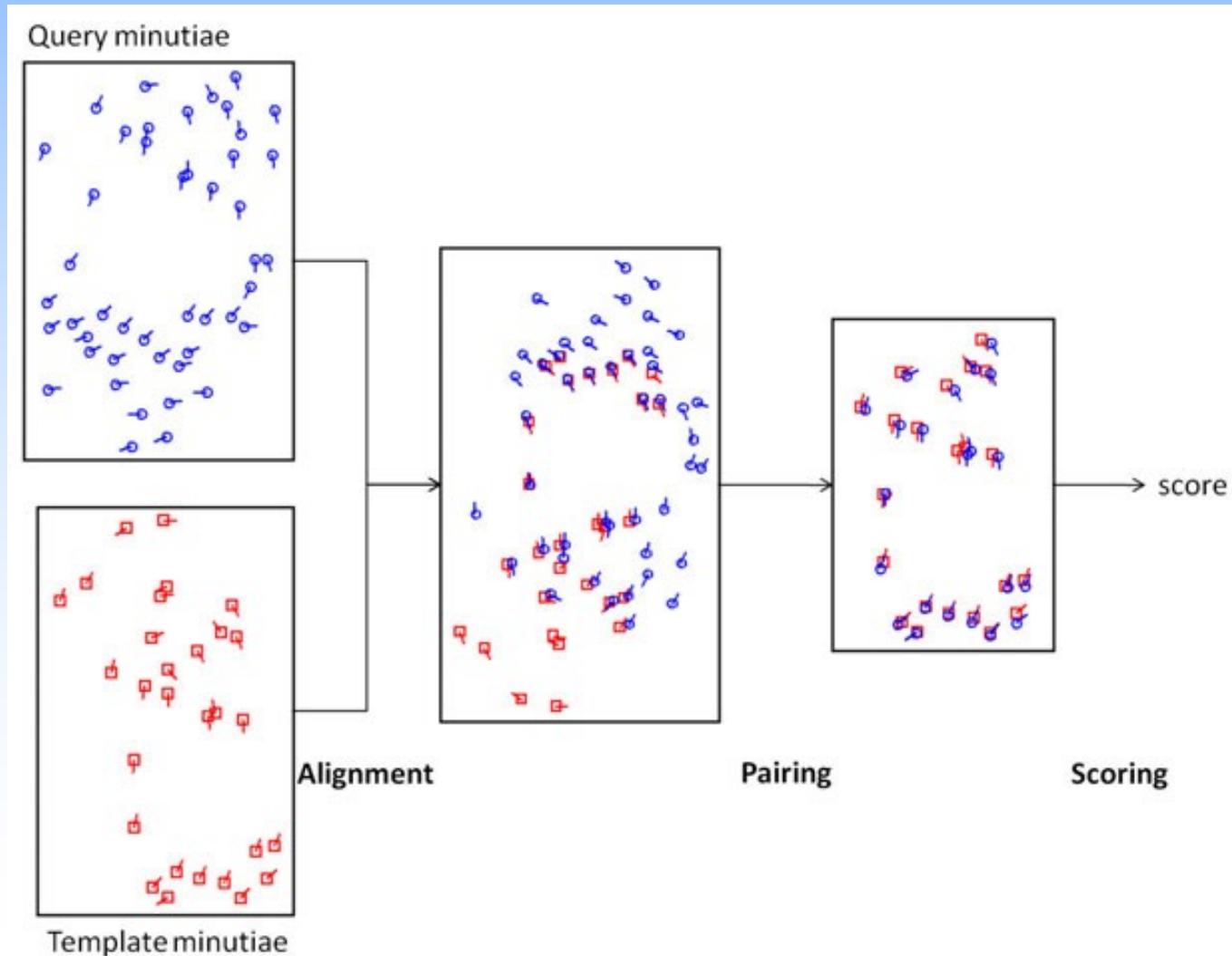
Two impressions of a user' s finger (capacitive)

Minutiae Correspondence

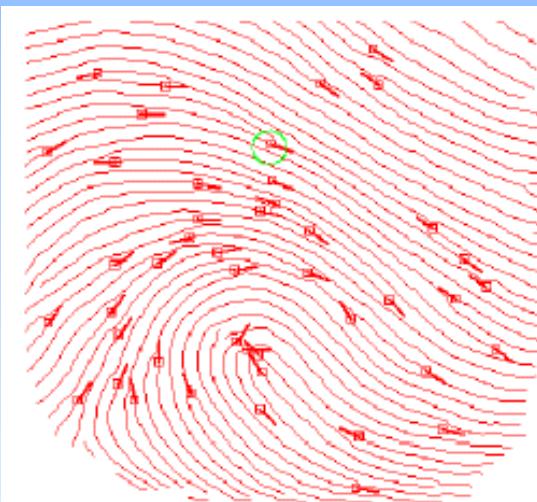


Minutiae matching

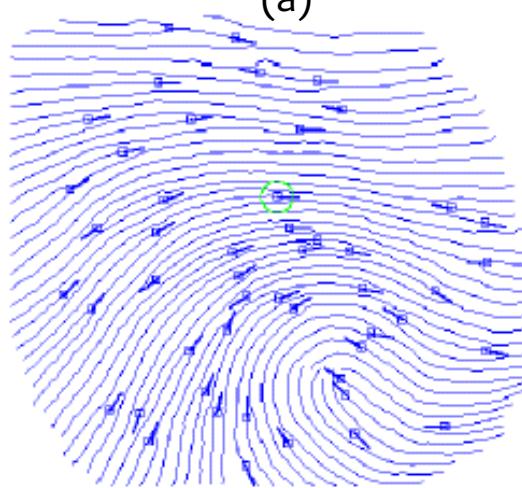
Almost all fingerprint matchers are based on minutiae matching



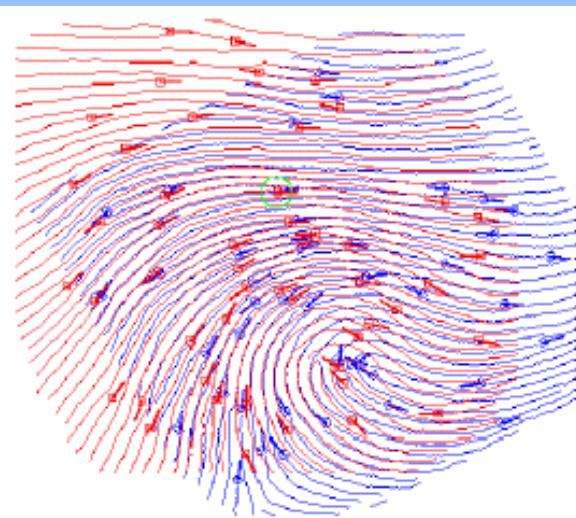
Minutiae Matching Result



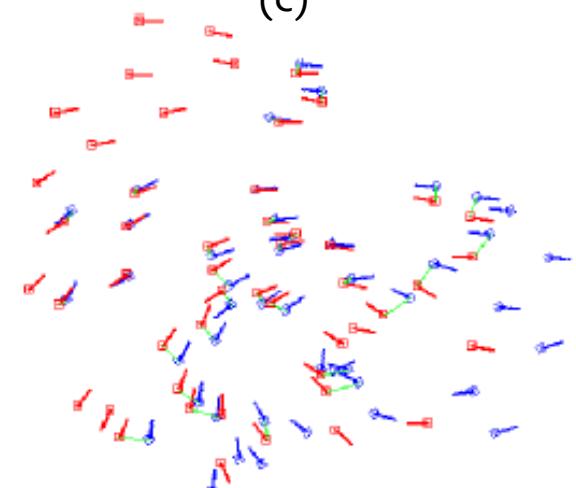
(a)



(b)



(c)



(d)

Minutiae Matching Scores



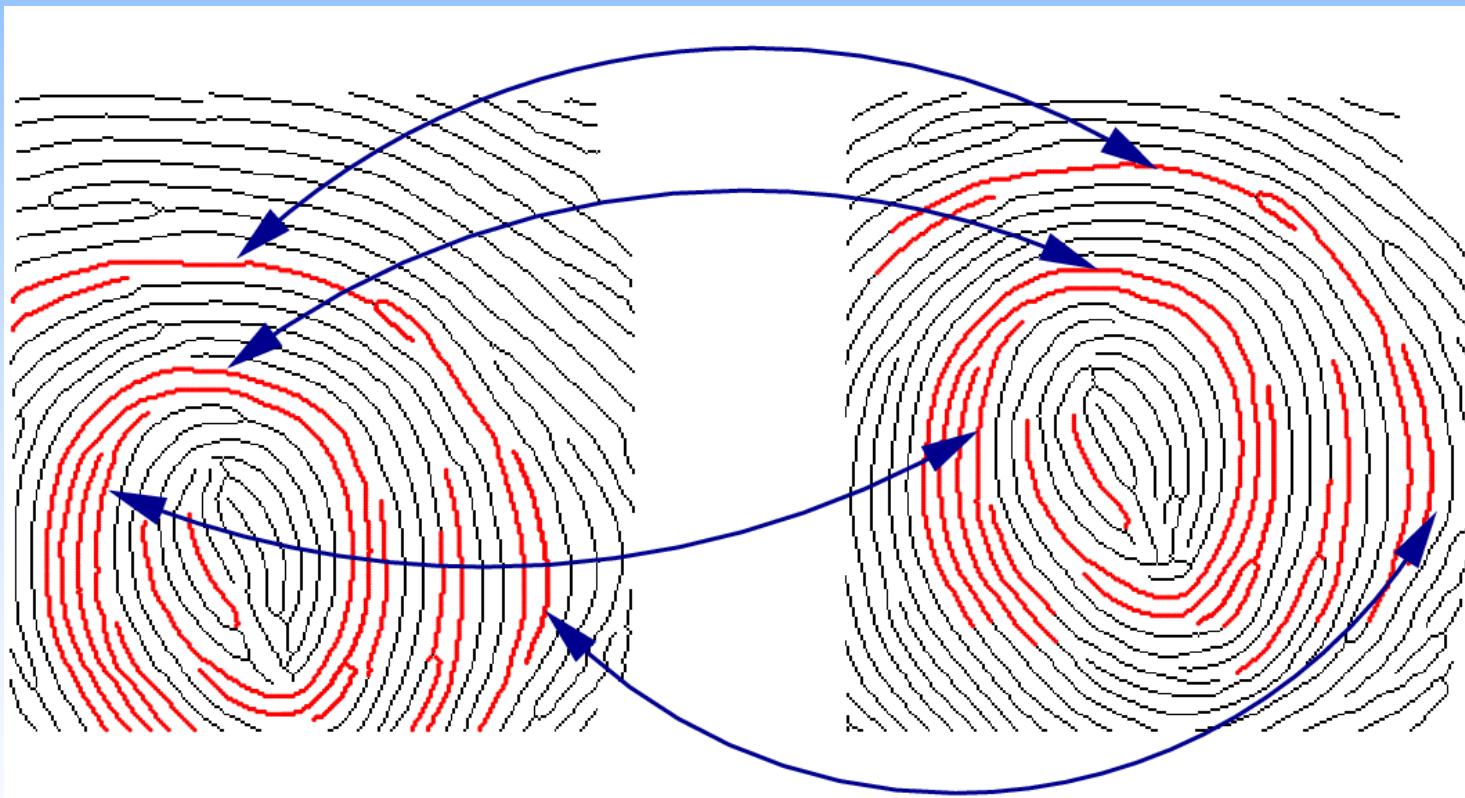
(a)

(b)

(c)

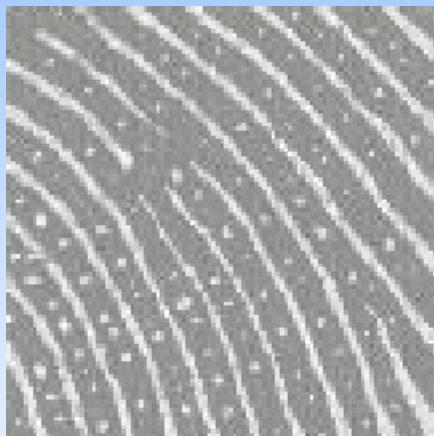
$$S_{ab} = 97; S_{bc} = 5; S_{ac} = 2$$

Ridge Correspondence

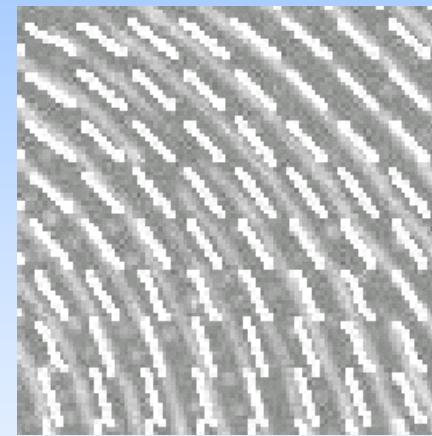


Some sensors have a small surface area, resulting in fewer minutiae points
So use the ridge information also

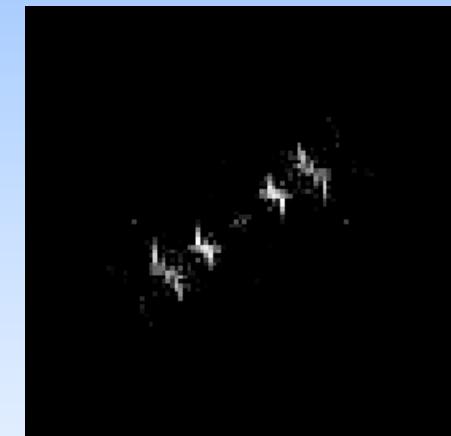
Fingerprint as Oriented Texture



(a) Ridges in local region



(b) Ridge directions in (a)



(c) Fourier spectrum of (a)

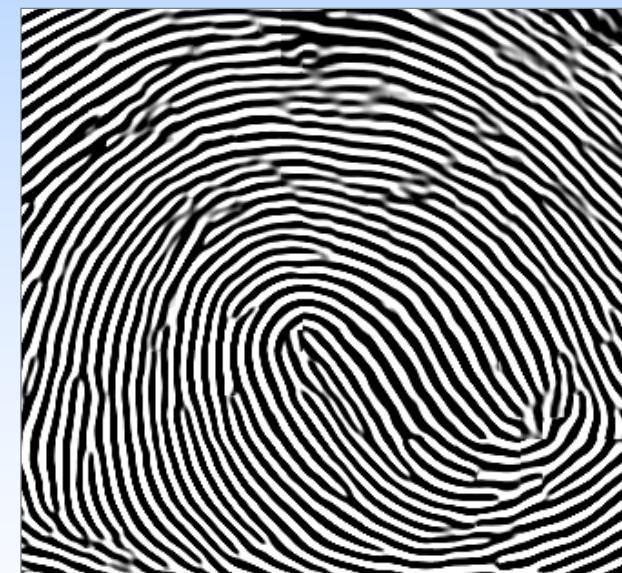
The ridge pattern in a fingerprint may be viewed as an **oriented texture pattern** having a fixed dominant spatial frequency and orientation in a local neighborhood. The frequency is due to the inter-ridge spacing present in the fingerprint and the orientation is due to the ridge flow pattern

Fingerprint Enhancement

- To address the problem of poor quality fingerprints



(a) Noisy image



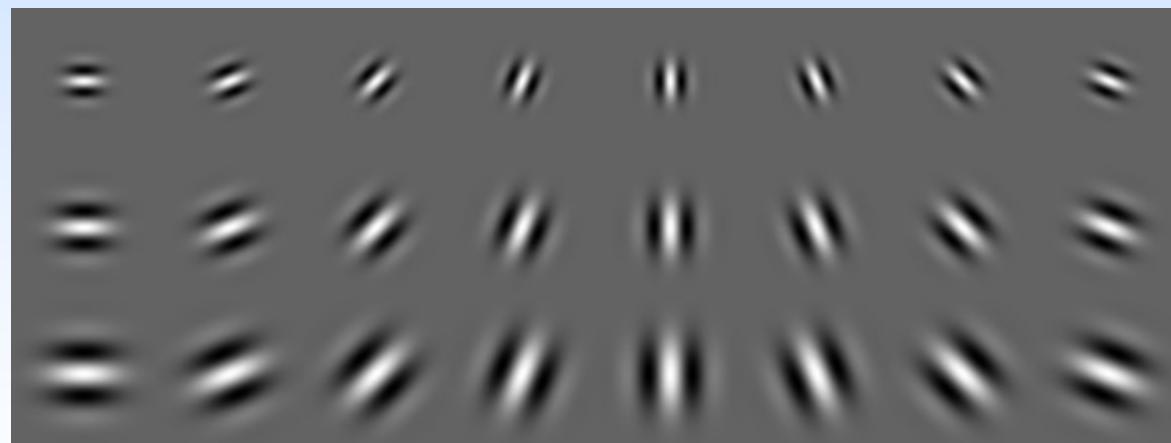
(b) Enhanced image

2D Gabor filters

2D Gabor wavelet:

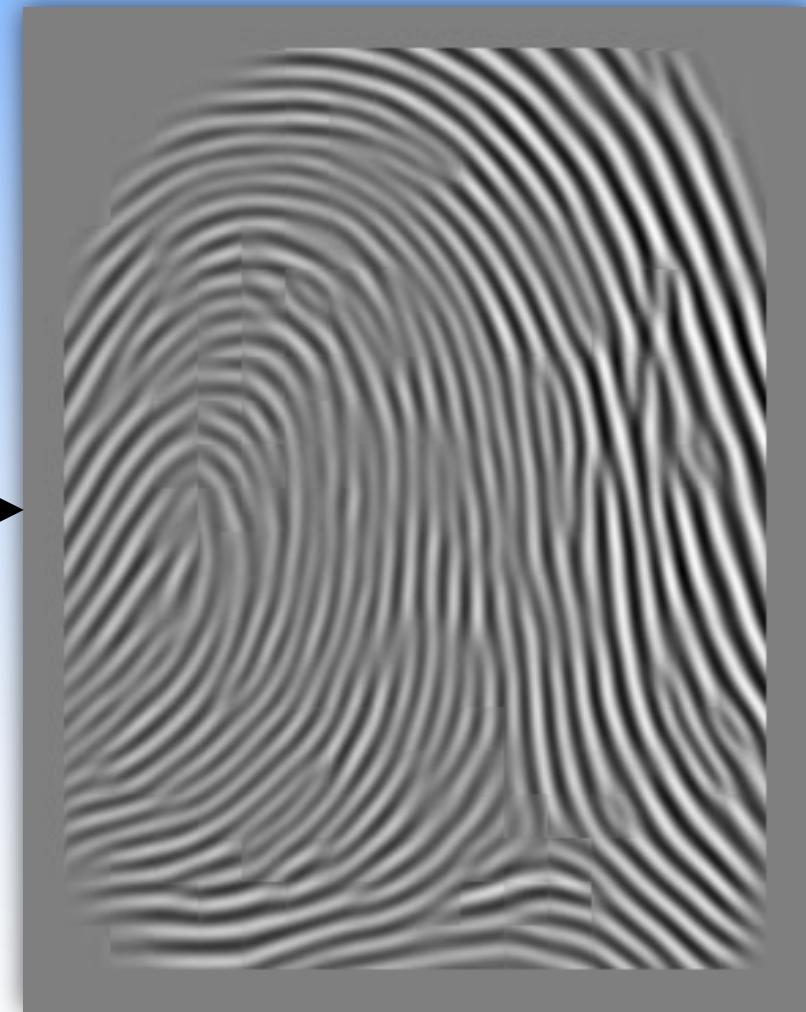
$$G(x, y) = e^{-\pi[(x-x_0)^2/\alpha^2 + (y-y_0)^2/\beta^2]} e^{-2\pi i[u_0(x-x_0) + v_0(y-y_0)]}$$

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 $\omega_0 = \sqrt{u_0^2 + v_0^2}$.



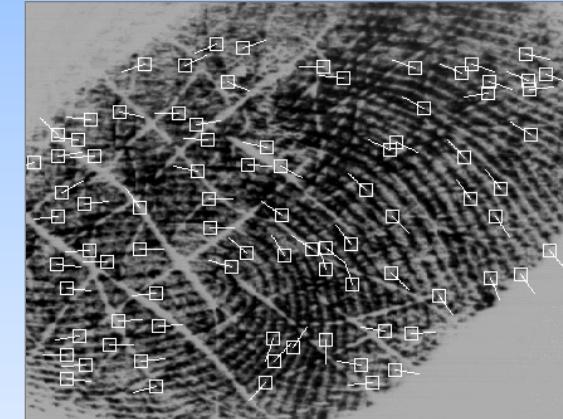
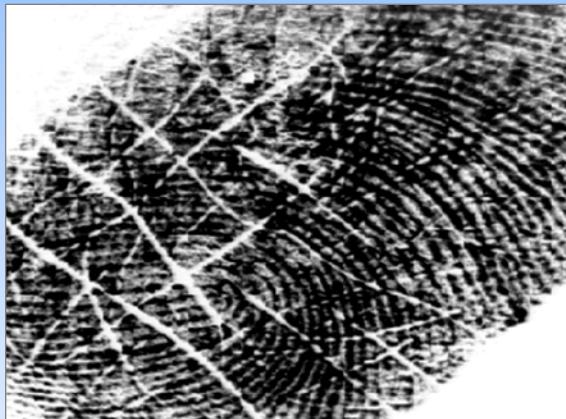
Real parts of Gabor filters (8 orientations and 3 scales)

Effect of Gabor filtering



Fingerprint Enhancement

A set of Gabor filters whose spatial characteristic is tuned to the inter-ridge spacing in fingerprints is used to enhance images



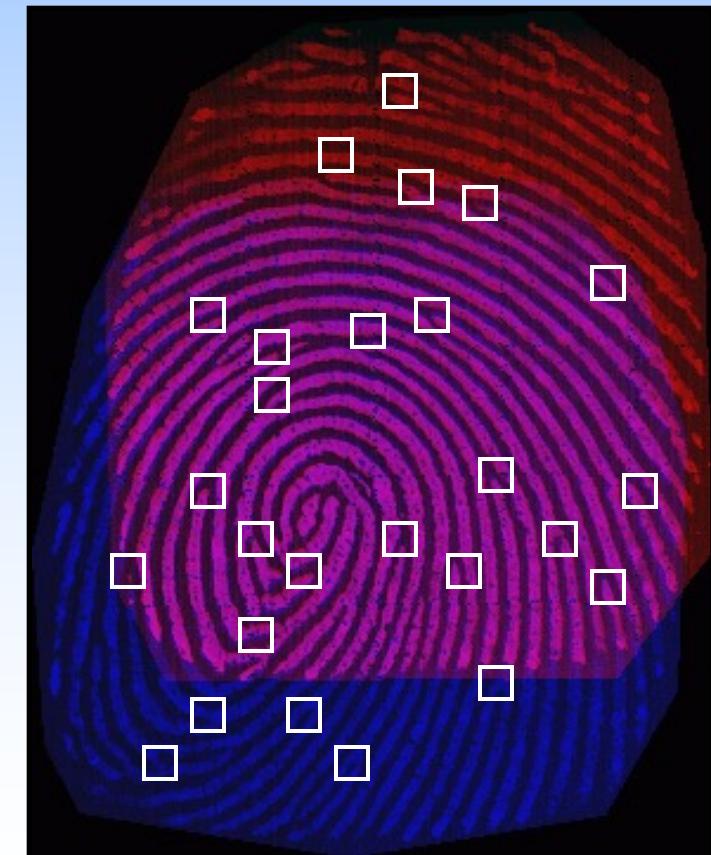
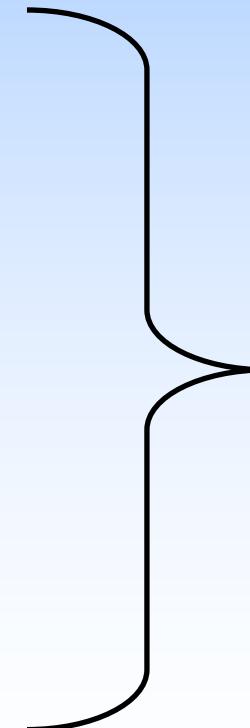
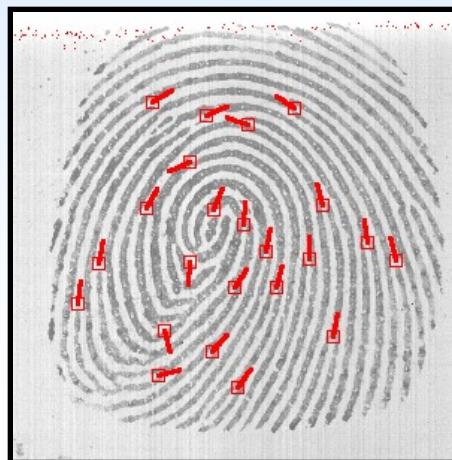
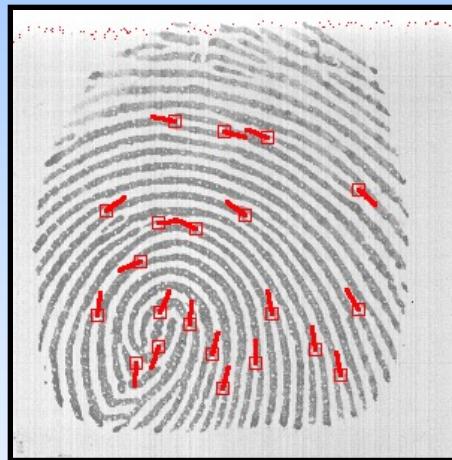
Minutiae extraction before enhancement



Minutiae extraction after enhancement

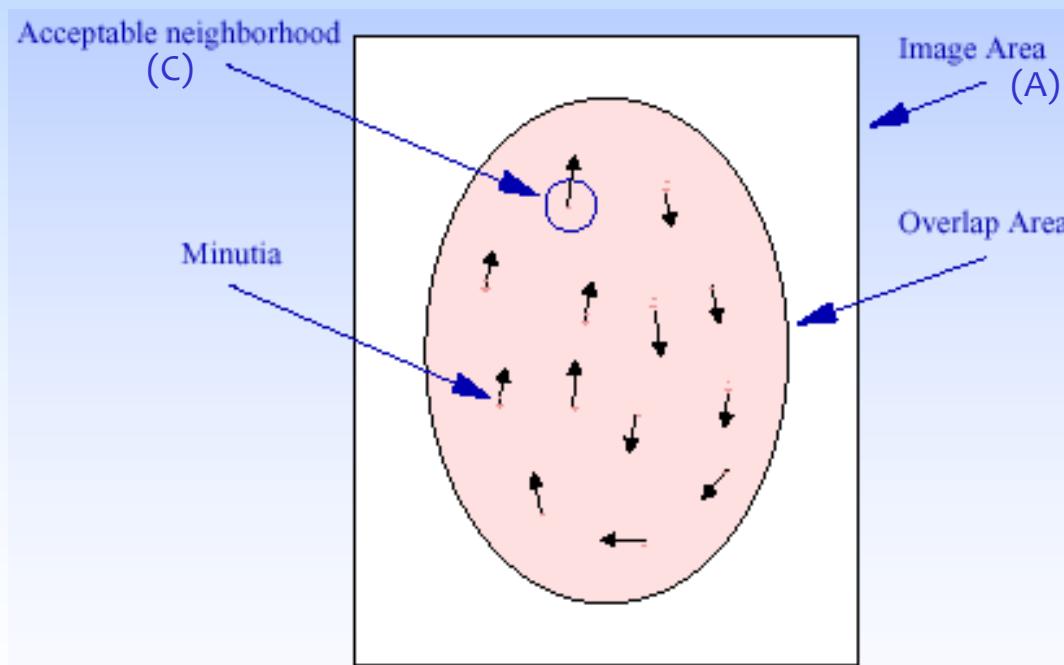
Fingerprint Mosaicking

Stitching two fingerprint impressions of a user to create a composite template comprising of more number of minutiae points and more texture information



Individuality of Fingerprints

- Given an input fingerprint with n minutiae, compute the probability that it will share q minutiae with any other template fingerprint containing m minutiae, $p(M, m, n, q)$. The corresponding minutiae should “match” in location and orientation.



$$(a) M = A/C = 52 \\ m=n=q=26 \\ P = 2.40 \times 10^{-30}$$

$$(b) M=A/C = 52 \\ m=n=26, q=10 \\ P = 5.49 \times 10^{-4}$$

*Pankanti, Prabhakar, Jain, "On the Individuality of Fingerprints", IEEE Transactions on PAMI, Vol. 24, No. 8, pp. 1010-1025, 2002.

Challenges in Fingerprint Recognition

- Cuts and bruises on finger; dry or oily finger
- Wear and tear of sensor
- Compact sensors capture only a small portion of the fingerprint
- Fingerprint impression is often left on the sensor
- Non-universality of fingerprint
- Changes in sensor technology (so interoperability across sensors)
- Latent fingerprints
- Spoof attacks (presentation attacks)
- How unique is a fingerprint?

