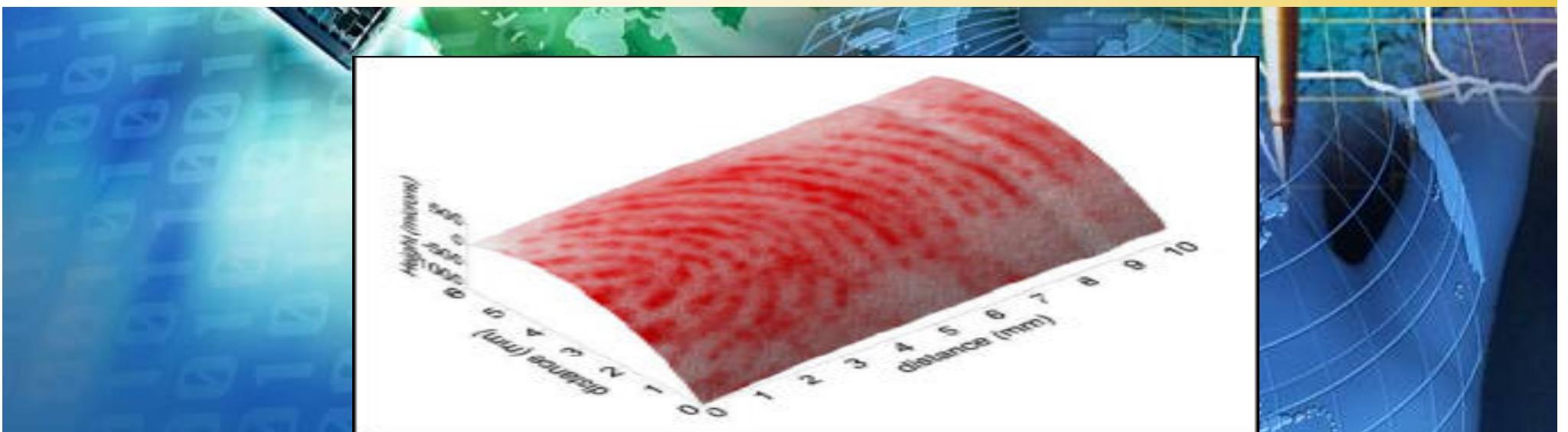




Fingerprint Recognition



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Data SecurTy Applied Research Lab

Outline

- ❖ Introduction
- ❖ Fingerprint features
 - 3 levels of features
 - Acquisition
 - Extraction
- ❖ Fingerprint matching
- ❖ Fingerprint synthesis
- ❖ Palmprint and applications
- ❖ Summary

Introduction

- ❖ In 1684, an English plant morphologist, [Nehemiah Grew](#), published the 1st scientific paper reporting his systematic study on the ridge, furrow, and pore structure
- ❖ In 1788, a detailed description of the anatomical formations of fingerprints was made by [Mayer](#), the German anatomist
- ❖ In 1823, [Purkinji](#) (a Czech physiologist) proposed the 1st fingerprint classification, which classified into 9 categories, but he did not mention any possibility of using fingerprints to identify people
- ❖ [Sir Francis Galton](#) (Darwin's cousin) introduced the minutiae features for fingerprint matching in late 19th century. He had calculated that the chance of a "false positive" was about 1/64 billion
- ❖ Automated Fingerprint Identification Systems (AFIS) were developed in the 1970s

Introduction

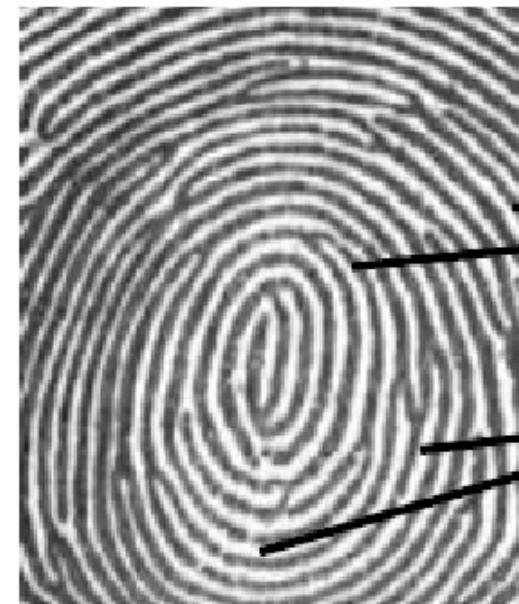
- ❖ Two types of human body skin



Smooth skin



Friction ridge skin

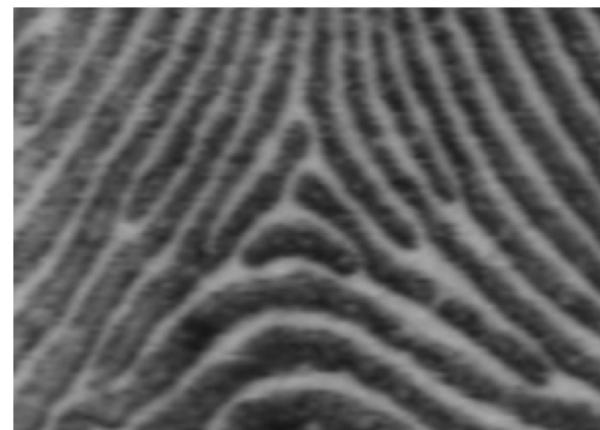
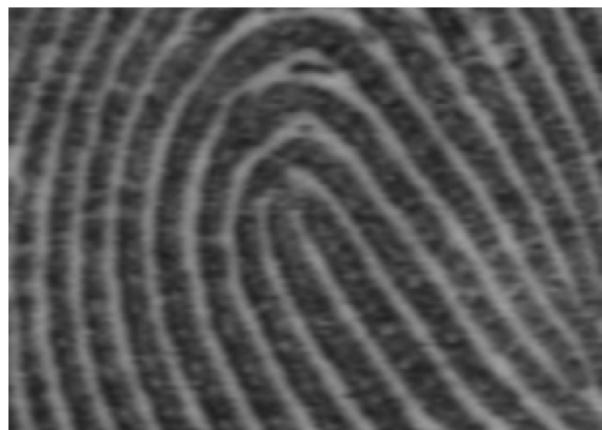


Ridges
Valleys

- ❖ Friction ridge skin is observed to have a pattern of ridges interspersed with valleys

Introduction

- ❖ A ridge orientation map typically contains some salient locations where the ridge orientations change abruptly → singular points
- ❖ Singular points: loop and delta



- ❖ A delta-type singularity indicates a local area where three ridge systems appear to meet

Introduction

- ❖ Fingerprint authentication refers to the automated method of verifying a match between two human fingerprints
- ❖ Fingerprints are one of many forms of biometrics used to identify individuals and verify their identity
- ❖ The analysis of fingerprints for matching purposes generally requires the comparison of several features of the print pattern
 - Patterns: aggregate characteristics of ridges
 - Minutiae points: unique features found within the patterns

Introduction

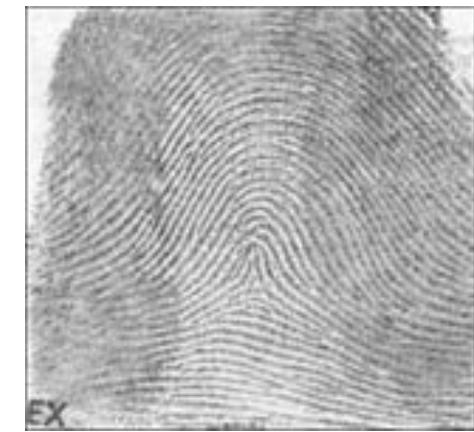
- ❖ In the Henry system of classification: 3 **basic** fingerprint patterns, i.e. loop, whorl, and arch, which constitute 60–65%, 30–35%, and 5% of all fingerprints, respectively (Wiki)



Loop (right)



Whorl



Arch

- ❖ Henry system of classification:
https://en.wikipedia.org/wiki/Henry_Classification_System

Introduction

❖ 3 basic patterns of fingerprint ridges:

- arch: the ridges enter from one side of the finger, rise in the center forming an arc, and then exit the other side
- loop: the ridges enter from one side of a finger, form a curve, and then exit on that same side
- whorl: ridges form circularly around a central point on the finger



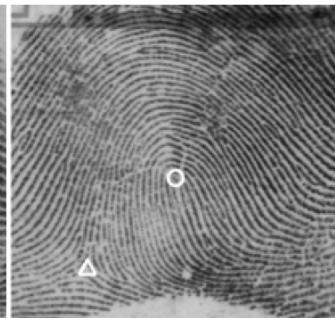
Plain arch



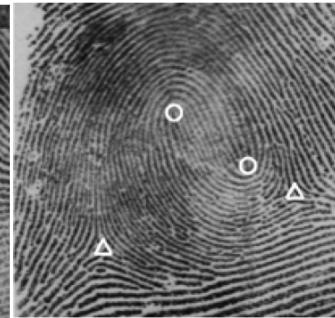
Tented arch



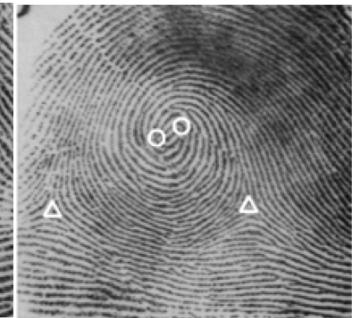
Left loop



Right loop



Twin loop



Whorl

Introduction

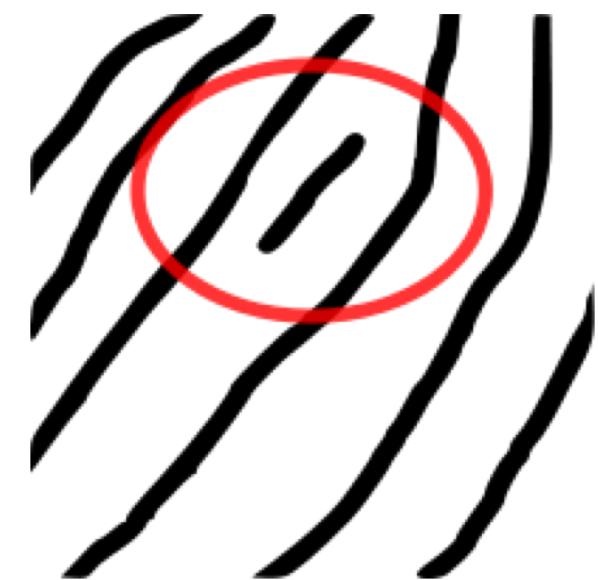
- ❖ Major minutiae features of fingerprint ridges are ridge ending, bifurcation, and short ridge (or dot)



Ridge ending



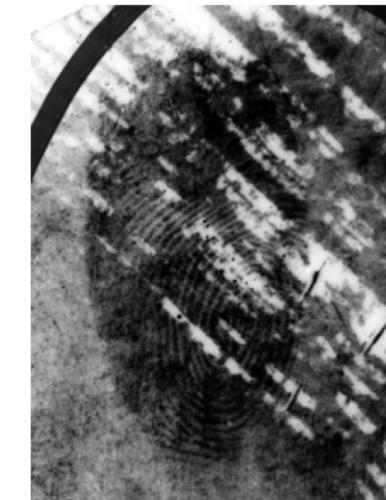
Bifurcation



Short ridge (dot)

Introduction

- ❖ 3 different fingerprint impressions: rolled, plain, and latent fingerprints

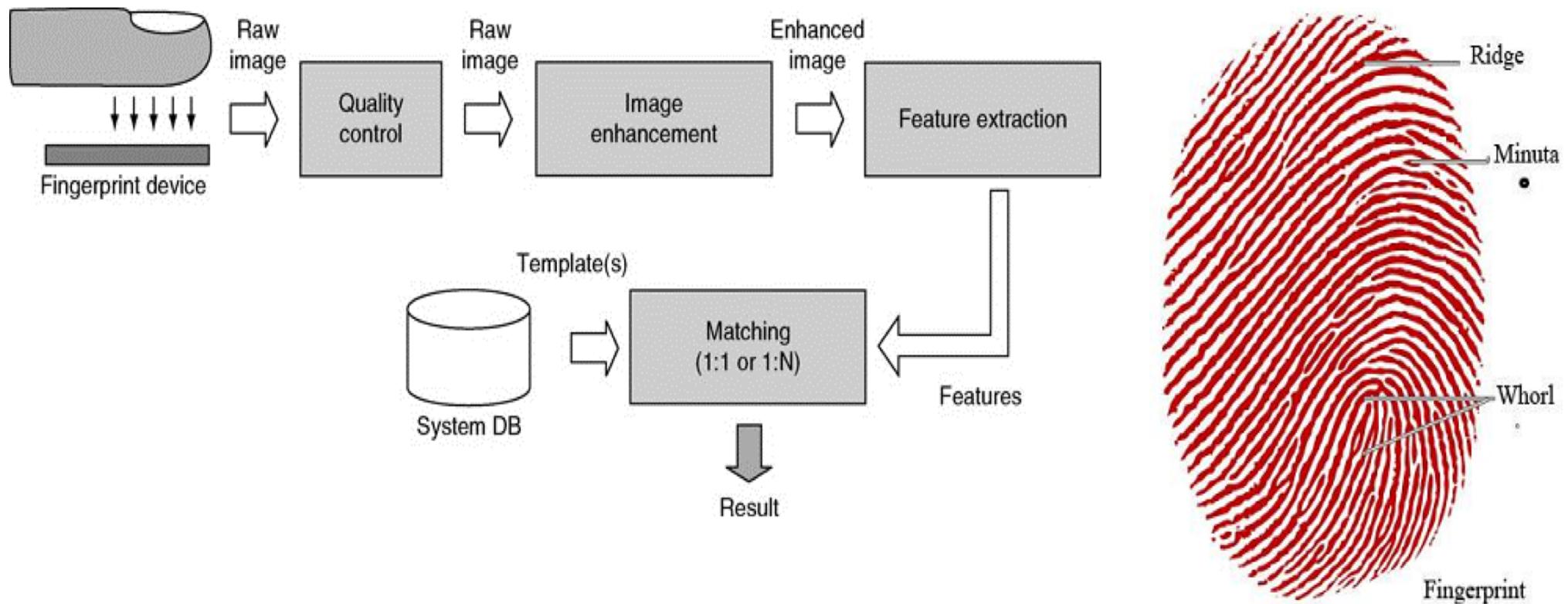


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Fingerprint feature extraction

❖ Typical system architecture:



Fingerprint features: 3 levels

- ❖ Fingerprint pattern, when analyzed at different scales, exhibits different types of features
 - global level (level 1) - delineates a ridge line flow pattern
 - local level (level 2) – minutiae details can be identified
 - very fine level (level 3) – intra-ridge details can be detected

Fingerprint features: 3 levels

❖ From handbook of fingerprint:

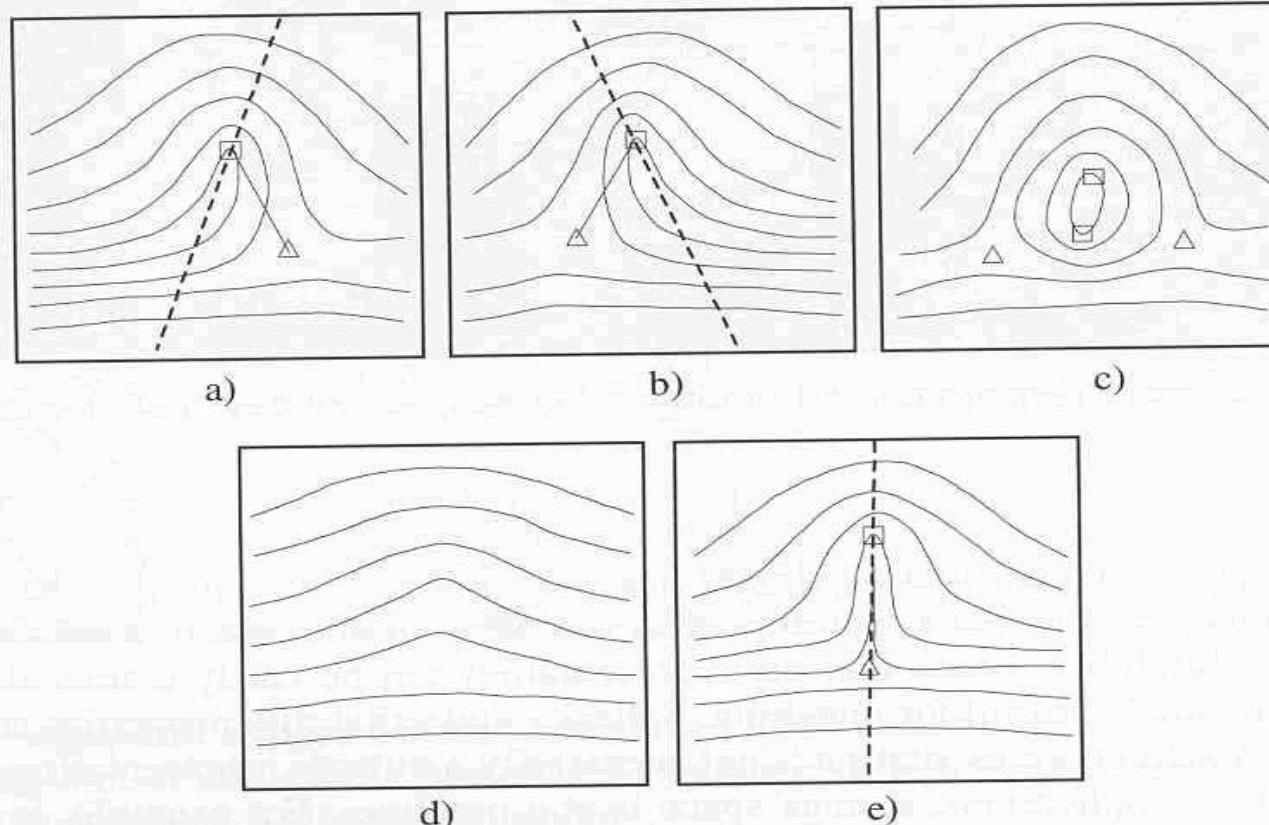


Figure 1.12. Fingerprint patterns as they appear at a coarse level: a) left loop; b) right loop; c) whorl; d) arch; and e) tented arch; squares denote loop-type singular points, and triangles delta-type singular points.

Fingerprint features: 3 levels

- ❖ From handbook of fingerprint:

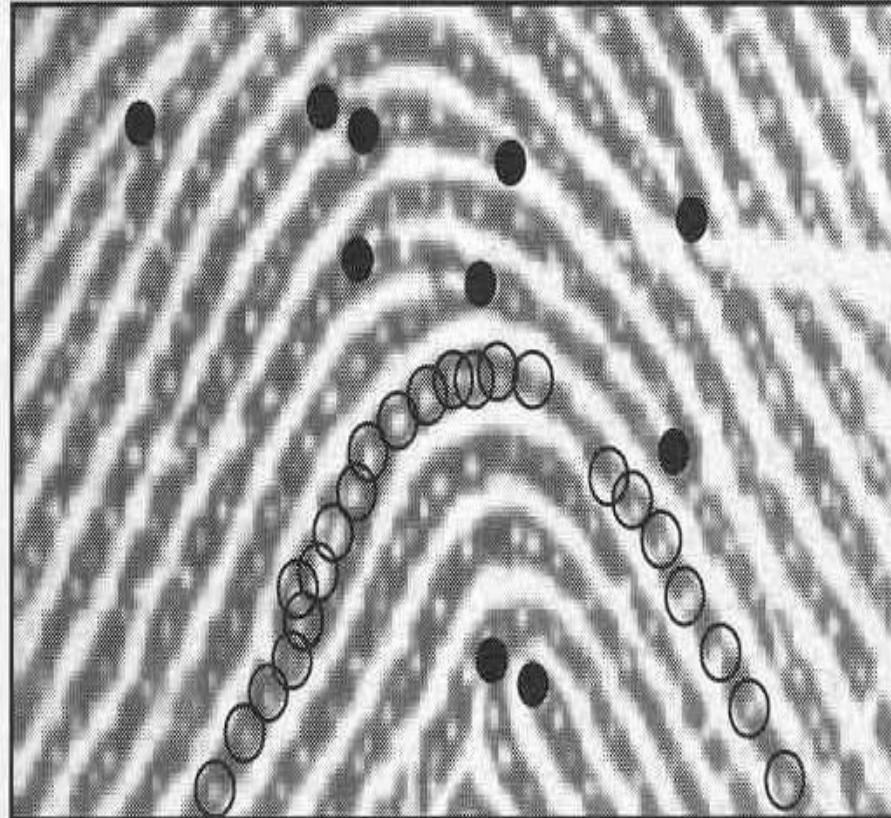


Figure 1.13. Minutiae (black-filled circles) in a portion of fingerprint image; sweat pores (empty circles) on a single ridge line.

Fingerprint features: 3 levels

- ❖ Fingerprint features at 3 different levels of detail:

(a) Rolled fingerprint in NIST SD29

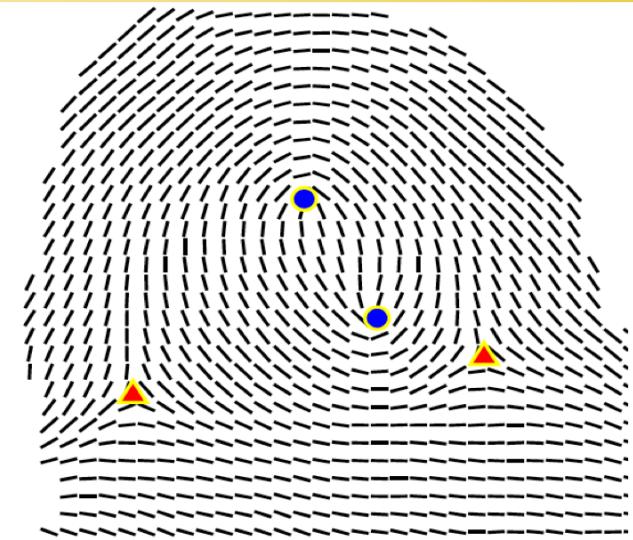
(b) Level-1 features:
orientation field and
singular points (cores/loops
marked as circles and
deltas marked as triangles)

(c) Level-2 features:
minutiae

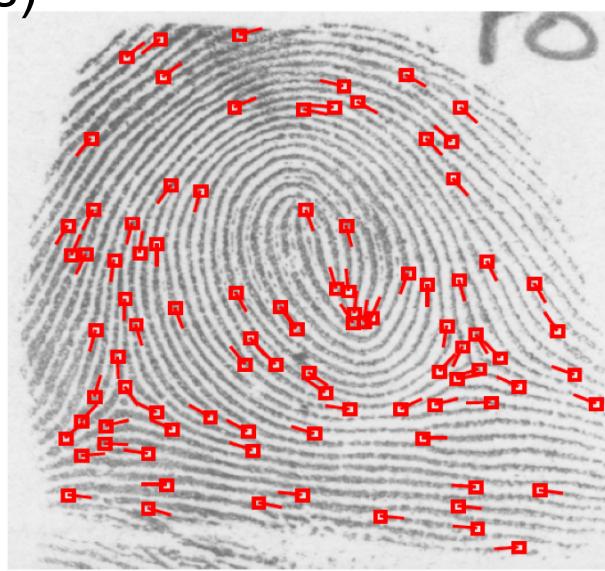
(d) Level-3 features:
incipient ridges



(a)



(b)



(c)



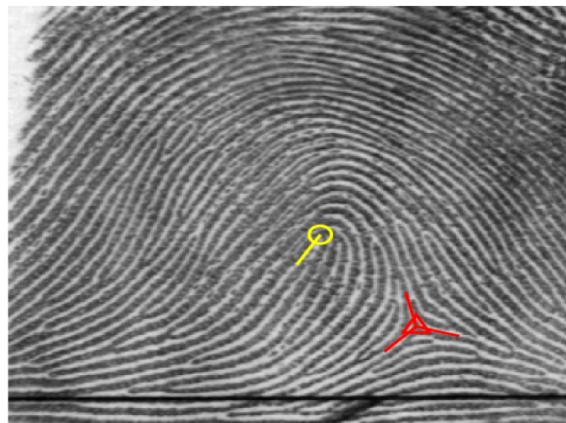
(d)

Fingerprint features: 3 levels

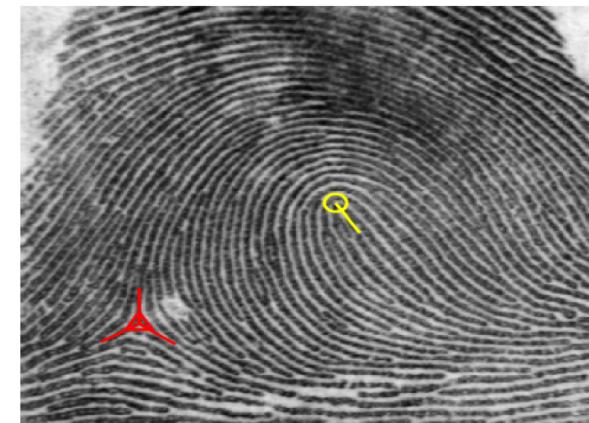
- ❖ More about fingerprint pattern types at level 1: (a) Arch, (b) left-loop, (c) right-loop, (d) tented-arch, (e) whorl, and (f) twin-loop. Core/loop is marked as yellow circle, and delta is marked as red triangle



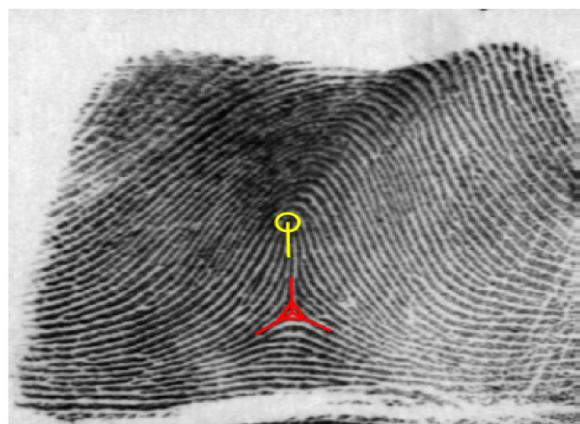
(a)



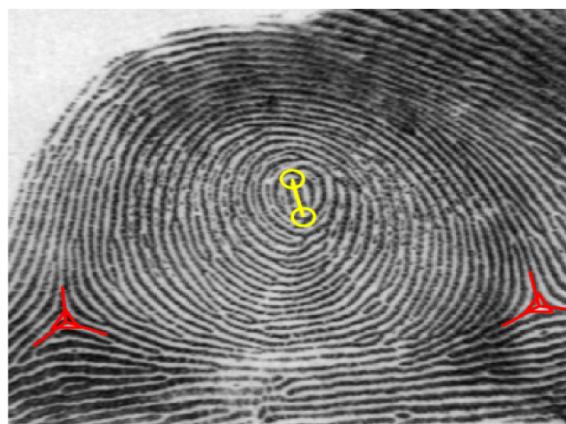
(b)



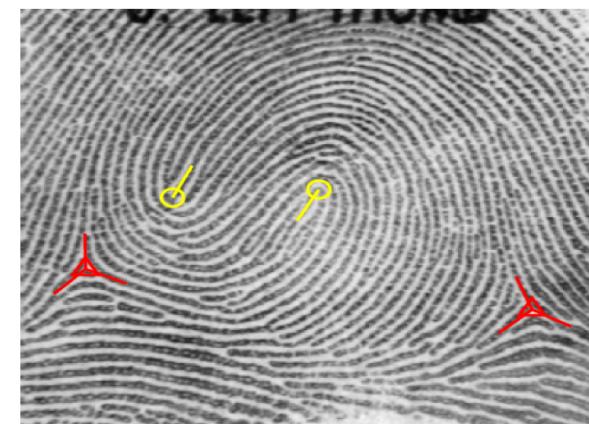
(c)



(d)



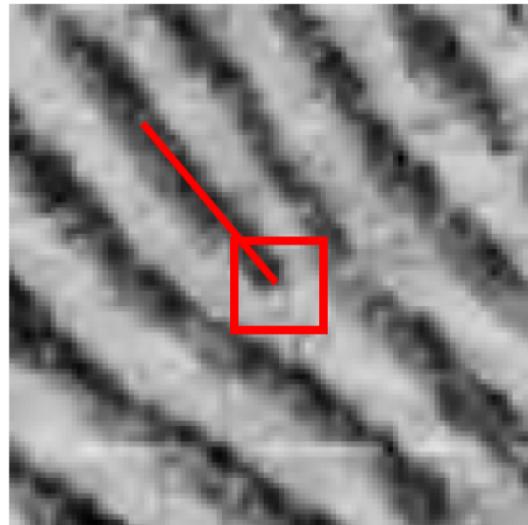
(e)



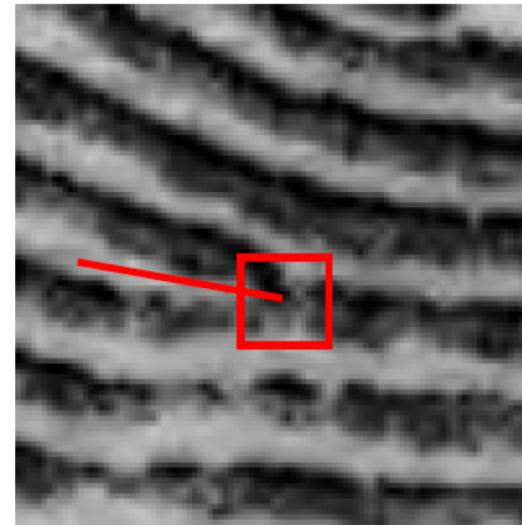
(f)

Fingerprint features: 3 levels

- ❖ More about fingerprint minutiae at level 2
- ❖ The simplest way of representing a minutia is by using a 3-tuple vector: (x, y, Θ) , where (x, y) is the position of the minutia and Θ is its direction



(a)

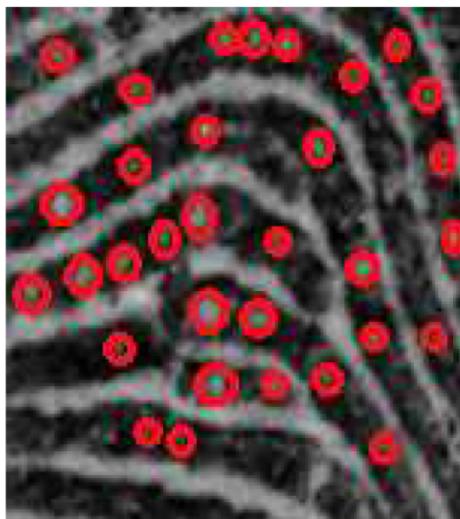


(b)

Minutia types in a fingerprint. (a) Ridge ending and (b) ridge bifurcation.

Fingerprint features: 3 levels

- ❖ More about fingerprint features at level 3
- ❖ Level-3 features in a fingerprint: (a) Pores, (b) incipient ridges, (c) dots, and (d) ridge edge protrusion
- ❖ Easier to observe in high resolution images (at least 1000 ppi as opposed to the typical resolution of 500 ppi used to collect fingerprint images)



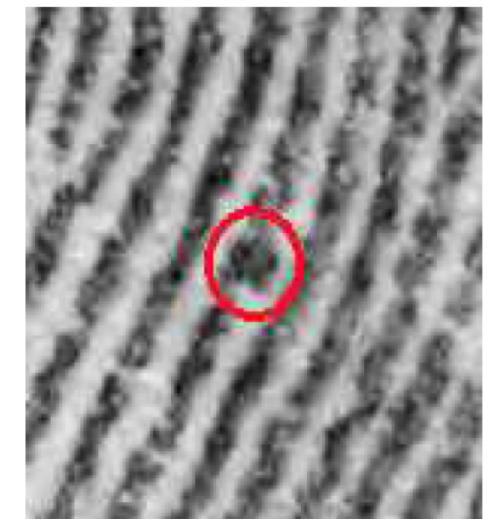
(a)



(b)



(c)



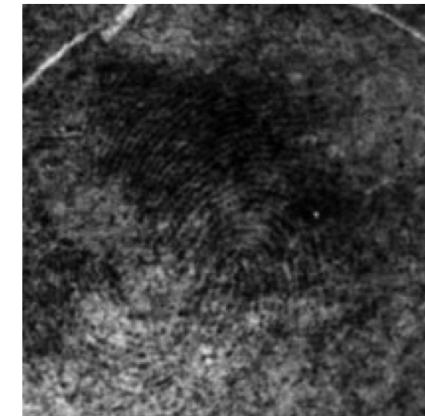
(d)

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Fingerprint features: acquisition

- ❖ The process of capturing and digitizing the fingerprint of an individual for further processing



- A fingerprint can be first transferred to a paper substrate by manually placing an inked fingertip on paper, and then digitizing the resulting impression using a flatbed scanner
- a live-scan fingerprint can be directly imaged from a finger based on a number of advanced sensing technologies
- A latent fingerprint can be lifted from objects in a crime scene using chemical or electrical processes

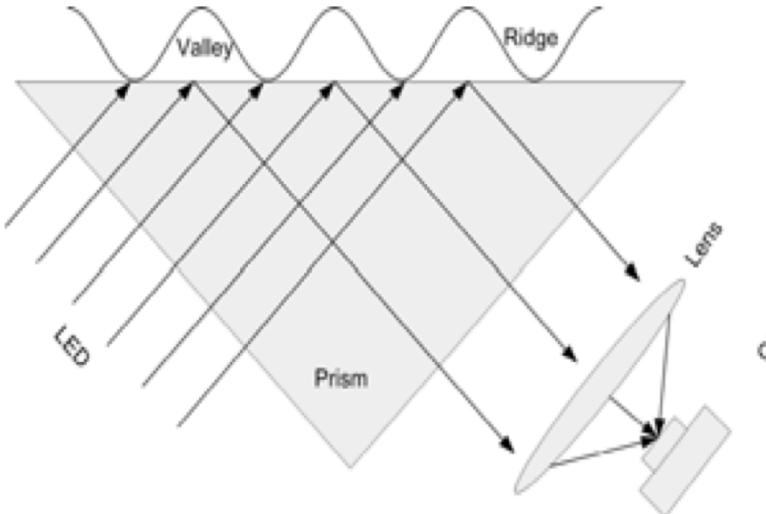
Fingerprint features: acquisition

- ❖ Most of the popular sensors to obtain a live-scan fingerprint image are based on either optical or solid-state technologies

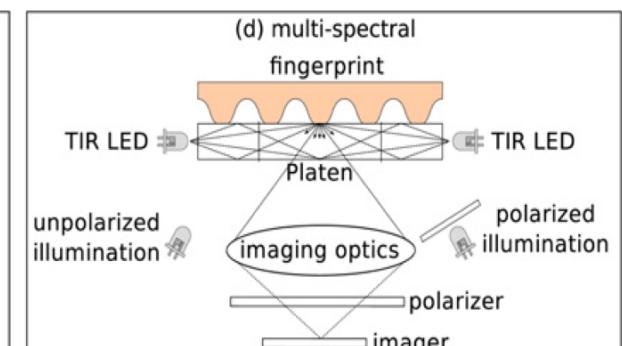
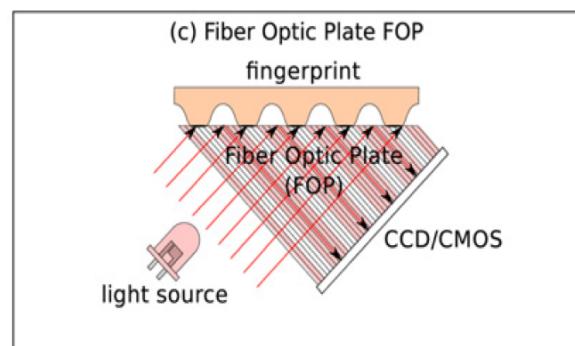
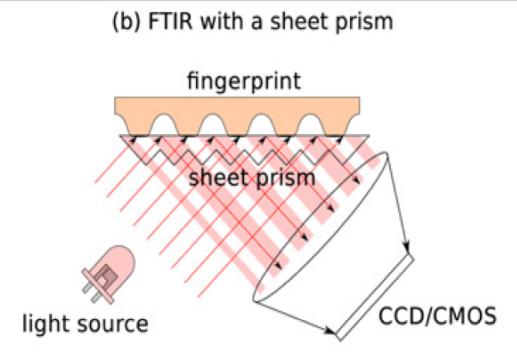
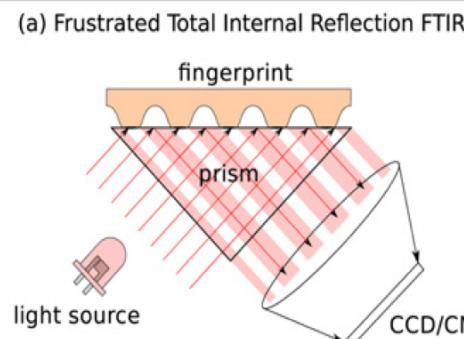


- ❖ Further details: cf. [2] section 2.3 & internet (for new technologies)

Fingerprint features: acquisition



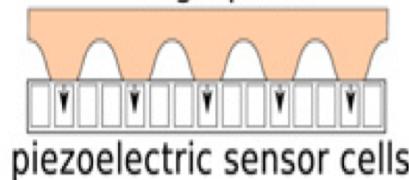
optical



Fingerprint features: acquisition

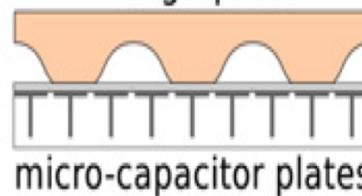
solid state

(e) pressure
fingerprint



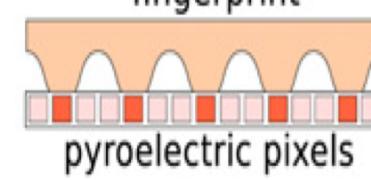
piezoelectric sensor cells

(f) capacitive
fingerprint



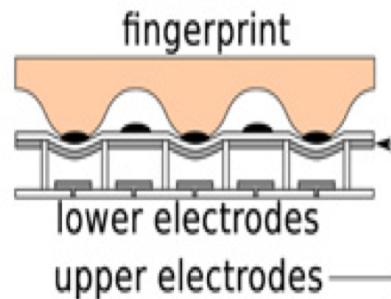
micro-capacitor plates

(g) thermal
fingerprint



pyroelectric pixels

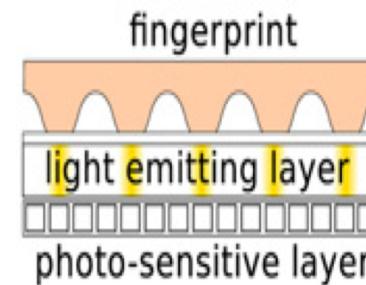
(h) micro-electromechanical MEMS



fingerprint

lower electrodes
upper electrodes

(i) electro-optical

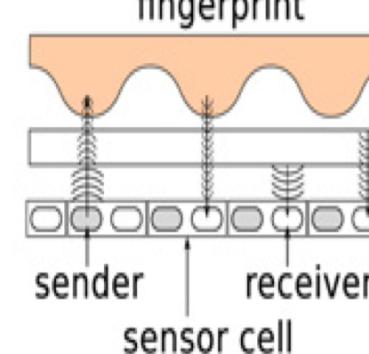


fingerprint

light emitting layer

photo-sensitive layer

(j) ultrasonic



fingerprint

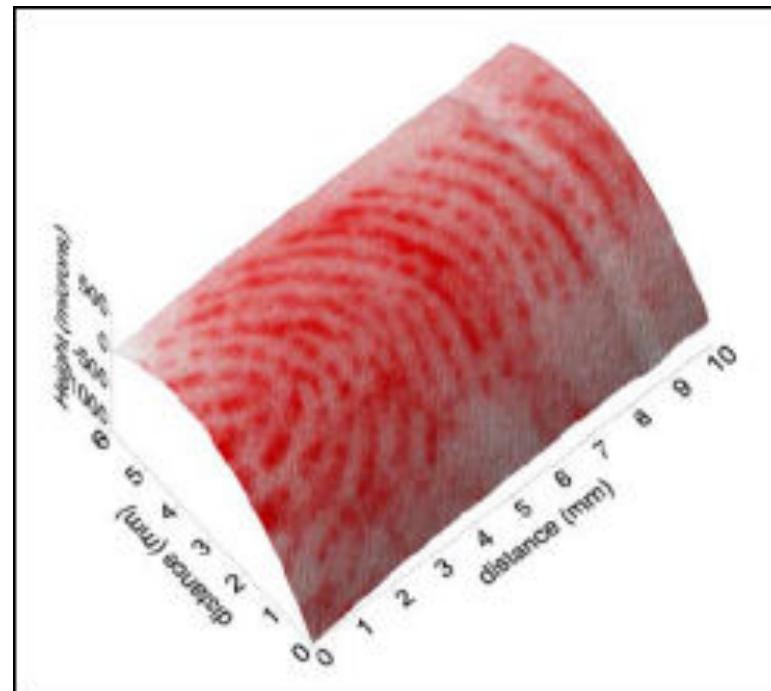
sender
receiver

sensor cell

- ❖ Apple's Touch ID uses a capacitance fingerprint sensor

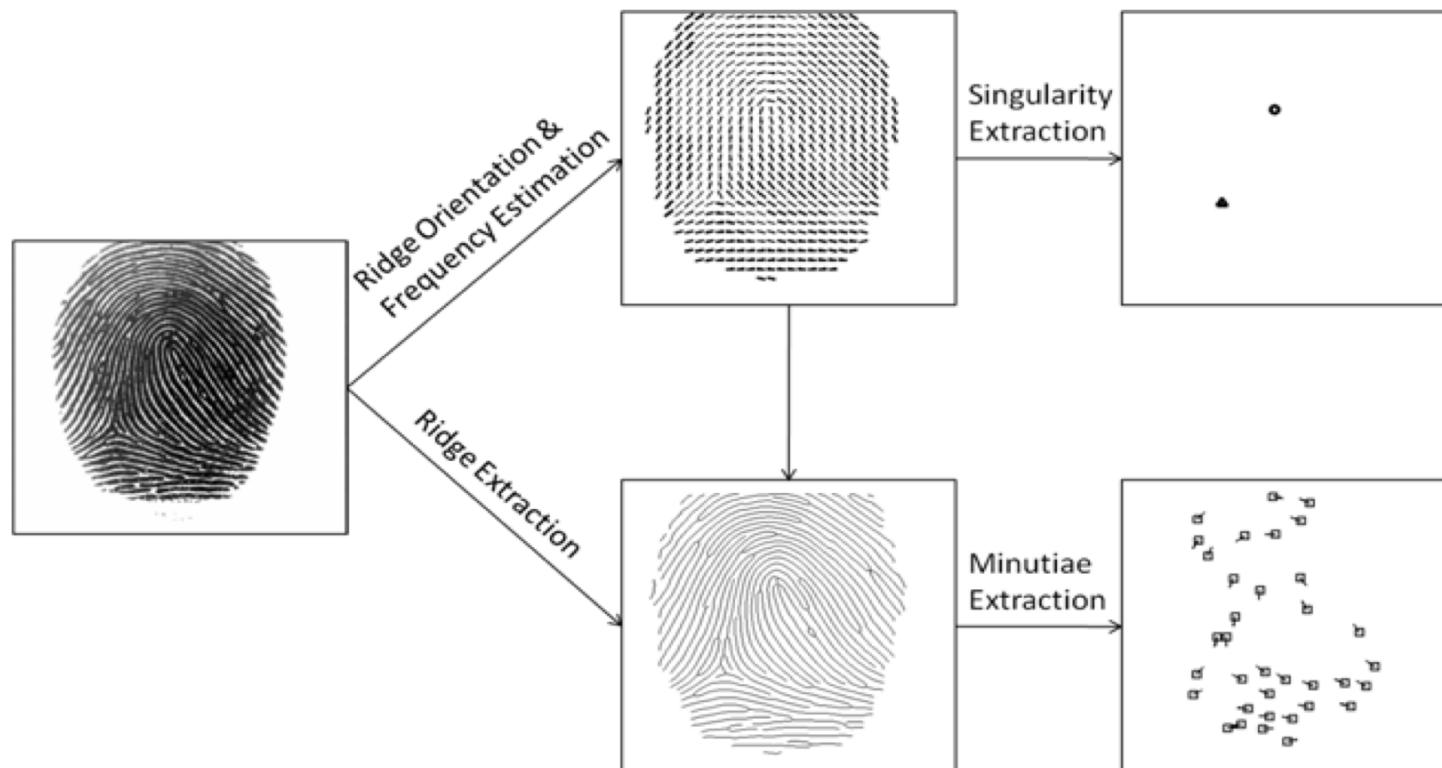
Fingerprint features: acquisition

- ❖ A new scanning Kelvin probe (SKP) fingerprinting technique, **no physical contact** with the fingerprint, has the potential to allow fingerprints to be recorded whilst still leaving intact material that could subsequently be subjected to DNA analysis



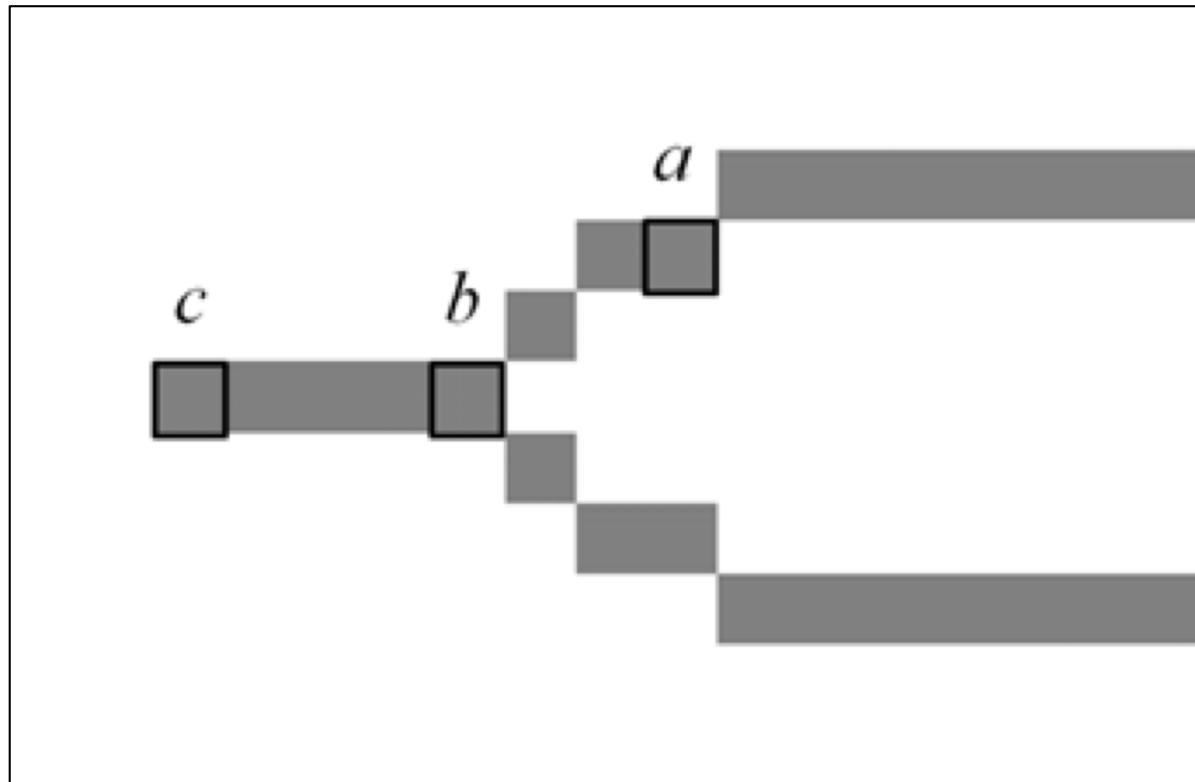
Fingerprint features: extraction

- ❖ Commercial fingerprint recognition systems are mainly based on Level 1 and Level 2 features
- ❖ Level 1 features are first extracted and then Level 2 features are extracted with the guidance of Level 1 features



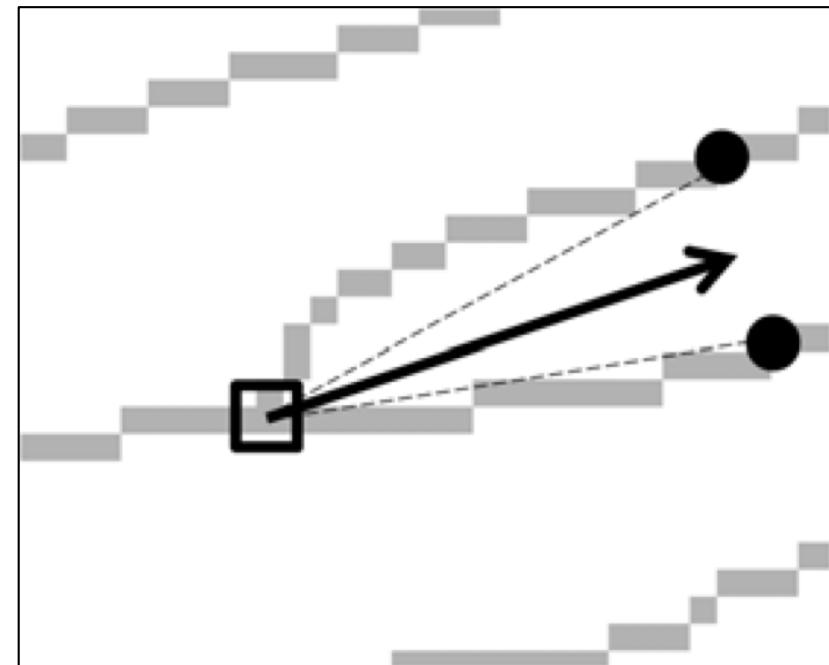
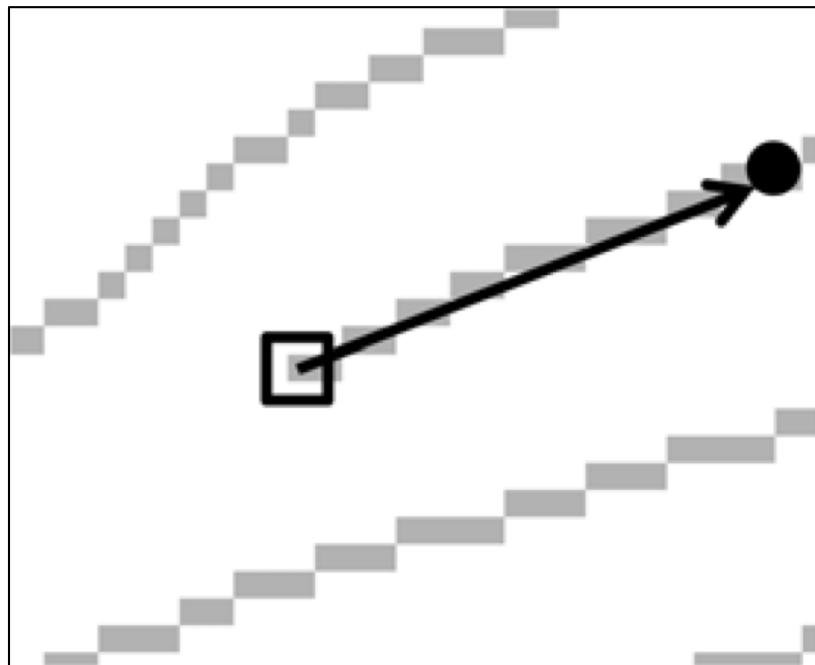
Fingerprint features: extraction

- ❖ Minutiae detection: 3 different types of ridge pixels are marked: typical ridge pixel ‘a’, ridge bifurcation ‘b’, and ridge ending ‘c’. Either a ridge bifurcation or a ridge ending defines a minutiae



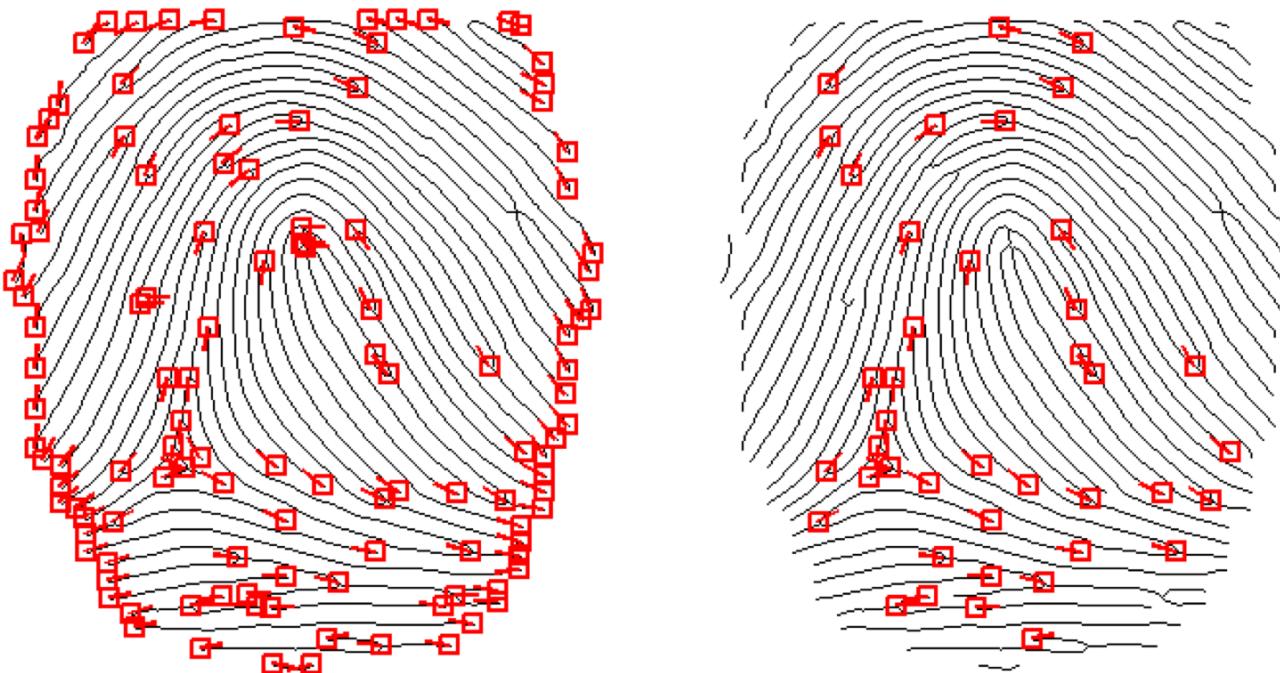
Fingerprint features: extraction

- ❖ Direction of a minutia: (a) Ridge ending and (b) ridge bifurcation



Fingerprint features: extraction

- ❖ Some of the minutiae detected may be spurious due to artifacts in image processing and noise in the fingerprint image
- ❖ Removing spurious minutiae: (a) Before minutiae filtering and (b) after minutiae filtering

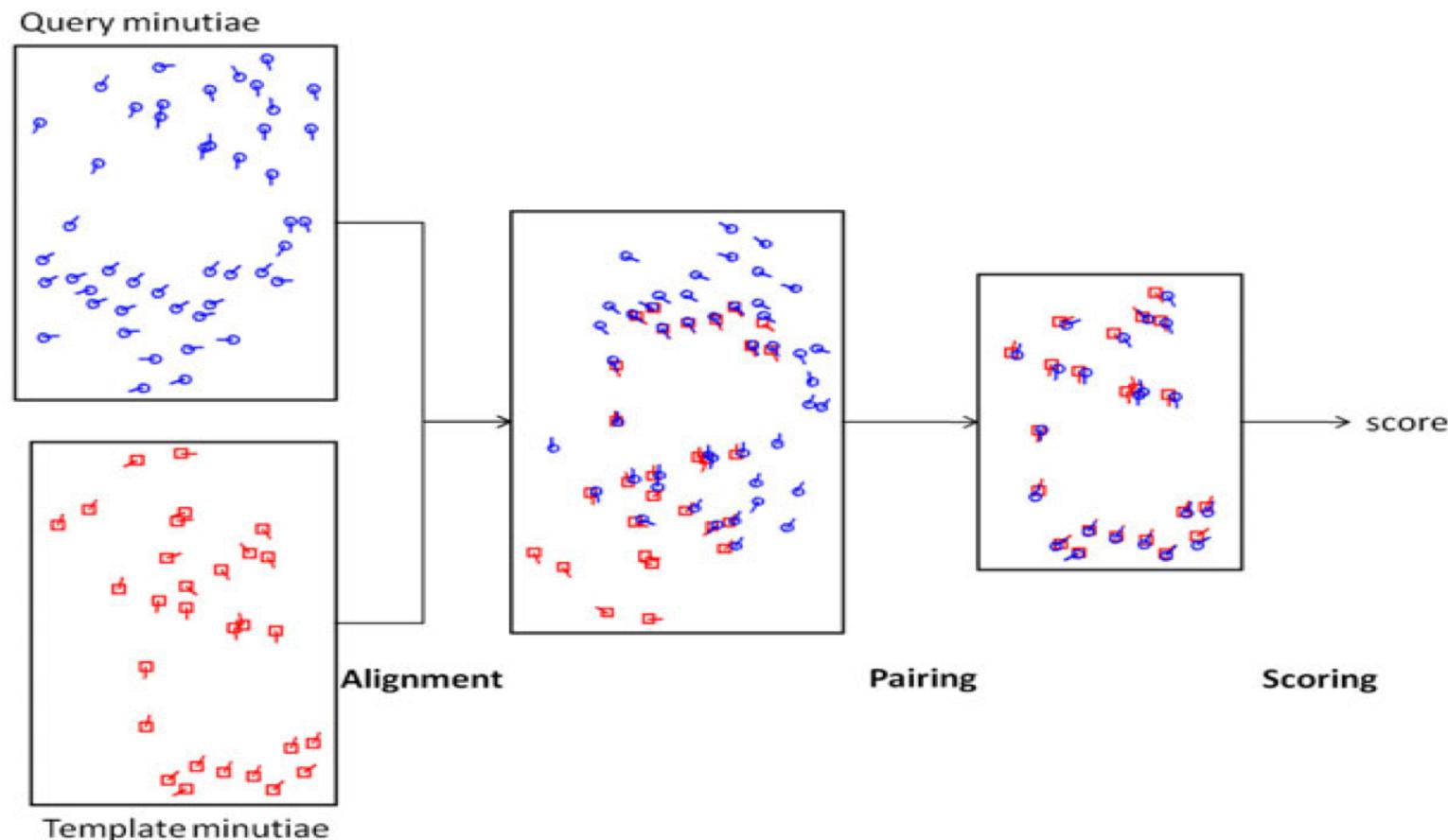


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Fingerprint matching

- Given the minutiae set $\{x_i^Q, y_i^Q, \theta_i^Q\}_{i=1}^M$ of a query fingerprint with M minutiae and the minutiae set $\{x_j^T, y_j^T, \theta_j^T\}_{j=1}^N$ of a template fingerprint with N minutiae. A simple matching algorithm which consists of three steps as follows:



Fingerprint matching

- ❖ Alignment: Determine the geometric transformation between the two minutiae sets so that they are in the same coordinate system

input : Two minutiae sets $\{x_i^T, y_i^T, \theta_i^T\}_{i=1}^M$ and $\{x_j^Q, y_j^Q, \theta_j^Q\}_{j=1}^N$

output: Transformation parameters

Initialize accumulator array A to 0

for $i = 1, 2, \dots, M$ **do**

for $j = 1, 2, \dots, N$ **do**

$$\Delta\theta = \theta_i^T - \theta_j^Q$$

$$\Delta x = x_i^T - x_j^Q \cos(\Delta\theta) - y_j^Q \sin(\Delta\theta)$$

$$\Delta y = y_i^T + x_j^Q \sin(\Delta\theta) - y_j^Q \cos(\Delta\theta)$$

$$A[\Delta\theta][\Delta x][\Delta y] = A[\Delta\theta][\Delta x][\Delta y] + 1$$

end

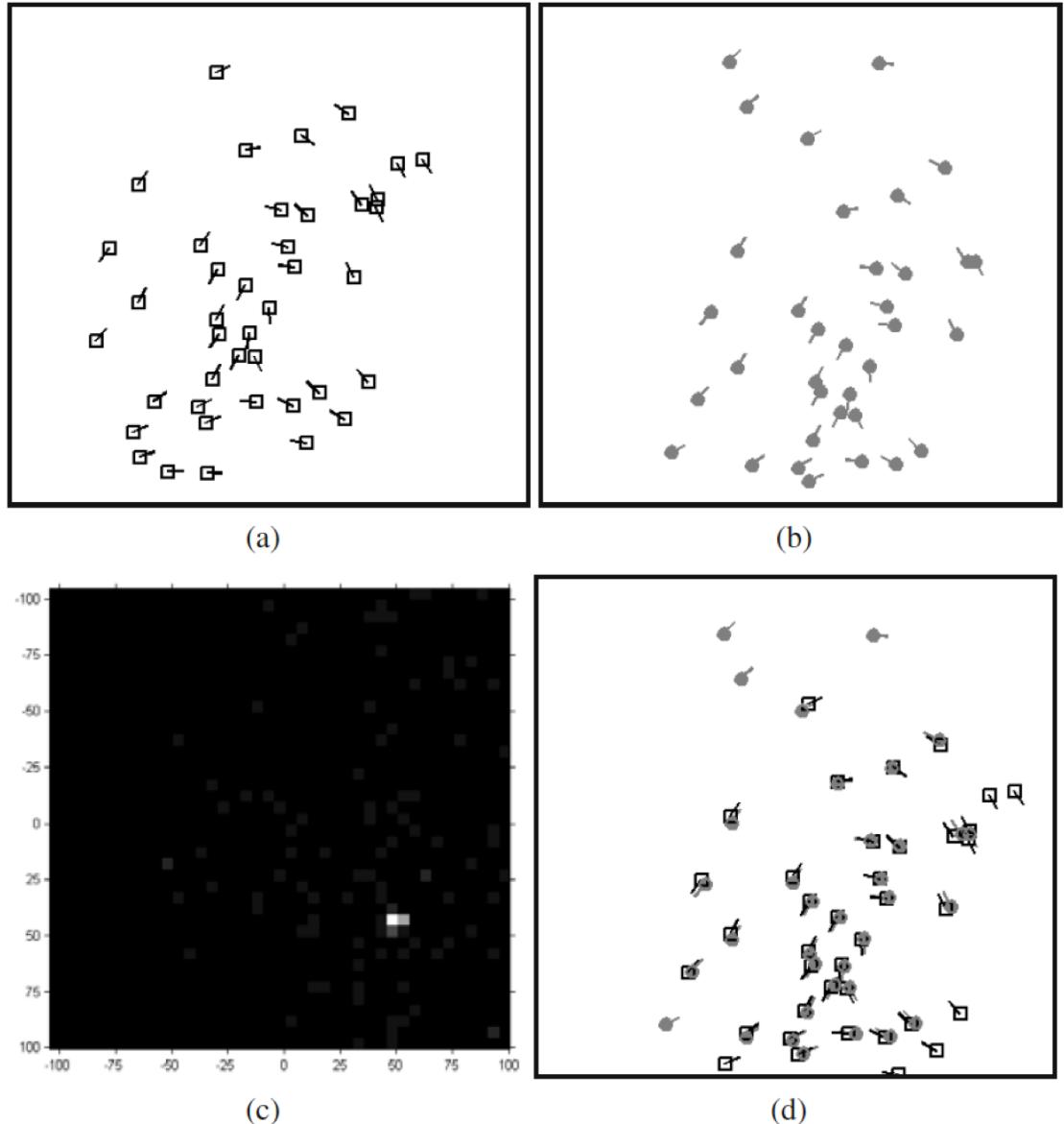
end

return location of peak in A

Algorithm 1: Determining transformation parameters for aligning two sets of fingerprint minutiae using the Generalized Hough Transform Algorithm.

Fingerprint matching

- ❖ Alignment-minutiae set alignment using the Hough transform:
 - (a) query minutiae set
 - (b) template minutiae set
 - (c) accumulator array or the Hough space image
 - (d) aligned minutiae sets
- ❖ The “bright” spot in the Hough space in (c) indicates the cell that receives the most votes. The x and y translation corresponding to this cell is used for aligning the two minutiae sets



Fingerprint matching

- ❖ Correspondence: Form pairs of corresponding minutiae
- ❖ After the 2 minutiae sets are aligned, the corresponding minutiae are paired
- ❖ A minutia a in the template minutiae set is said to be in correspondence with minutia b in the query minutiae set if and only if their distance is within a predefined distance threshold (say, 15 pixels) **and** the angle between their directions is within another predefined angle threshold (say, 20 degrees)
- ❖ One minutia in the template fingerprint is allowed to match to at most one minutia in the query fingerprint and vice versa

Fingerprint matching

❖ Correspondence

input : Two minutiae sets $\{x_i^T, y_i^T, \theta_i^T\}_{i=1}^M$ and $\{x_j^Q, y_j^Q, \theta_j^Q\}_{j=1}^N$;
Transformation parameters ($\Delta\theta, \Delta x, \Delta y$)

output: List of paired minutiae

Initialize: set flag arrays f^T, f^Q , and $count$ as 0; $list$ as empty

for $i = 1, 2, \dots, M$ **do**

for $j = 1, 2, \dots, N$ **do**

if $f^T[i] == 0 \& f^Q[j] == 0 \& \text{distance between minutiae } i \text{ and } j < t_d$
 & rotation between them $< t_r$ **then**

$f^T[i] = 1$

$f^Q[j] = 1$

$count = count + 1$

$list[count] = \{i, j\}$

end

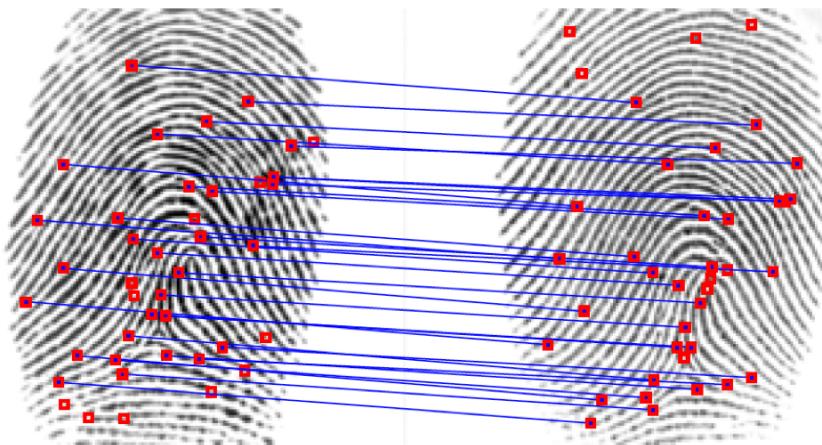
end

end

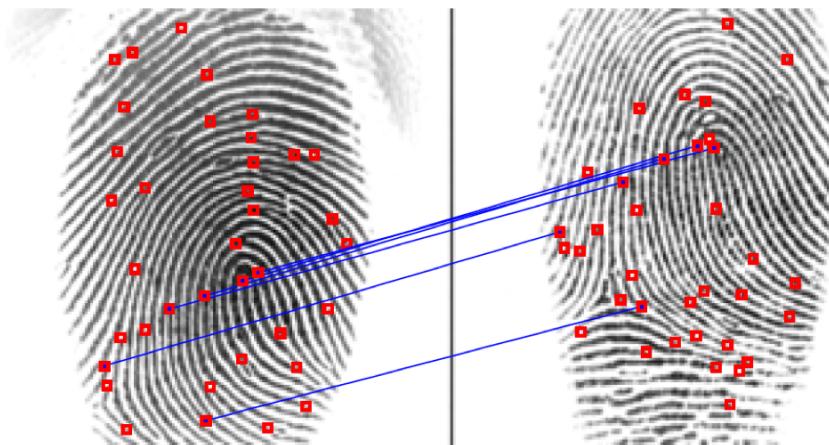
return $list$

Fingerprint matching

- ❖ Score generation: Compute the match score based on the corresponding minutiae points



(a) Match score = 614



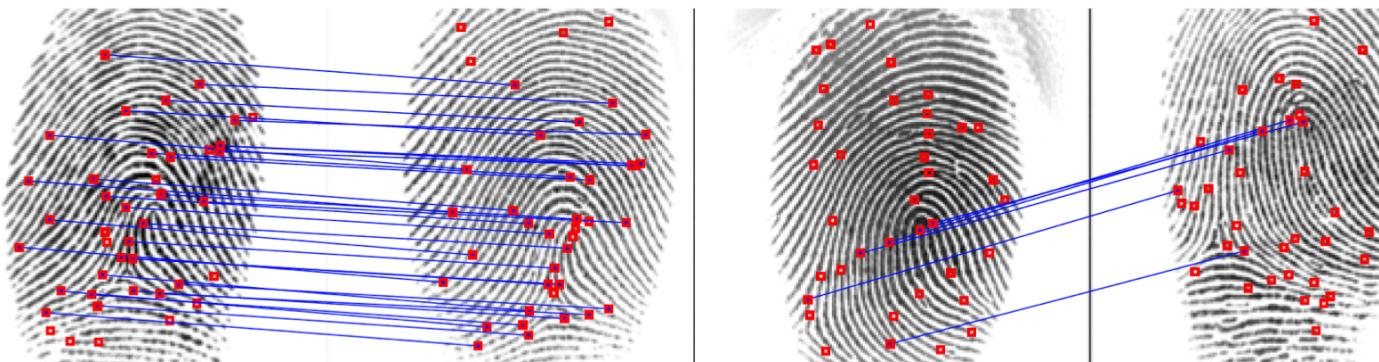
(b) Match score = 7

Neurotechnology VeriFinger SDK 4.2

Fig. 2.30 Fingerprint matching by a commercial matcher. (a) A genuine pair of fingerprints with 31 matched minutiae, and (b) an imposter pair with 6 matched minutiae. Corresponding minutiae between the two images are connected by lines. The match score is computed as some function of the number of matched minutiae and some other parameters that are proprietary to the commercial matcher.

Fingerprint matching

- ❖ Score generation: several potential features for distinguishing genuine matches from impostor matches can be examined
 - The first feature is the number of paired minutiae
 - The second useful feature is the percentage of matched minutiae in the overlapped area between the two fingerprints
 - It is intuitive that this percentage be larger for genuine matches than for impostor matches
 - Given a set of minutiae, the fingerprint area can be approximated by the convex hull of its minutiae points



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Fingerprint synthesis

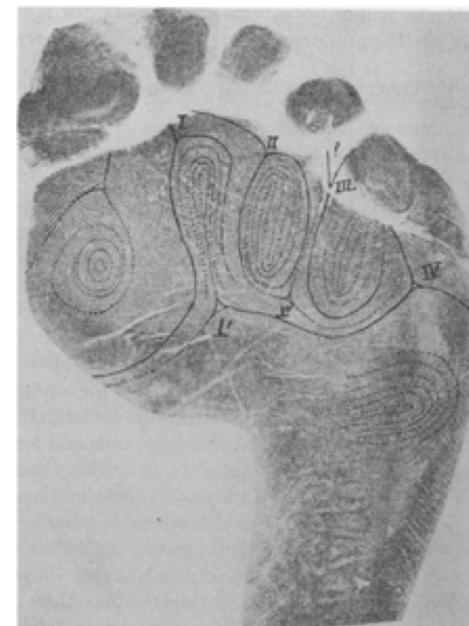
- ❖ Performance evaluation of fingerprint recognition systems is very data dependent
- ❖ To obtain tight confidence intervals at very low error rates, large databases of images are required and it is expensive
- ❖ To be able to model fingerprints and identify an appropriate set of parameters that characterize the fingerprints
- ❖ To solve this problem synthetic fingerprint images are introduced (for all levels of features)
- ❖ Further reading: [2]-section 2.7 & internet

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Palmpoint and applications

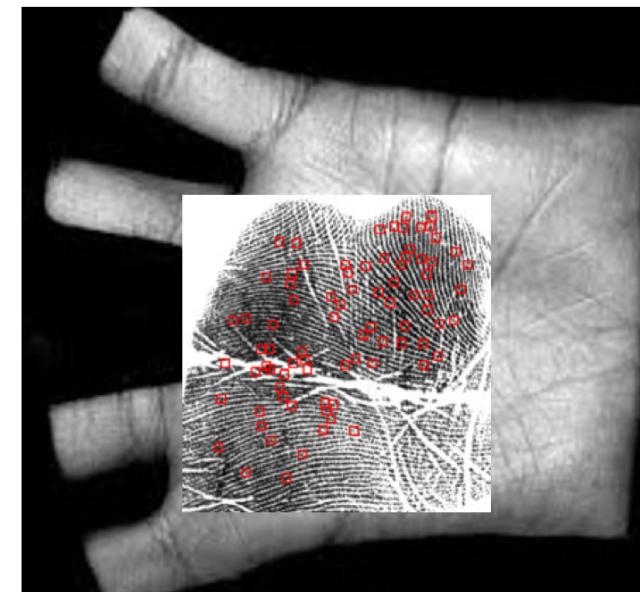
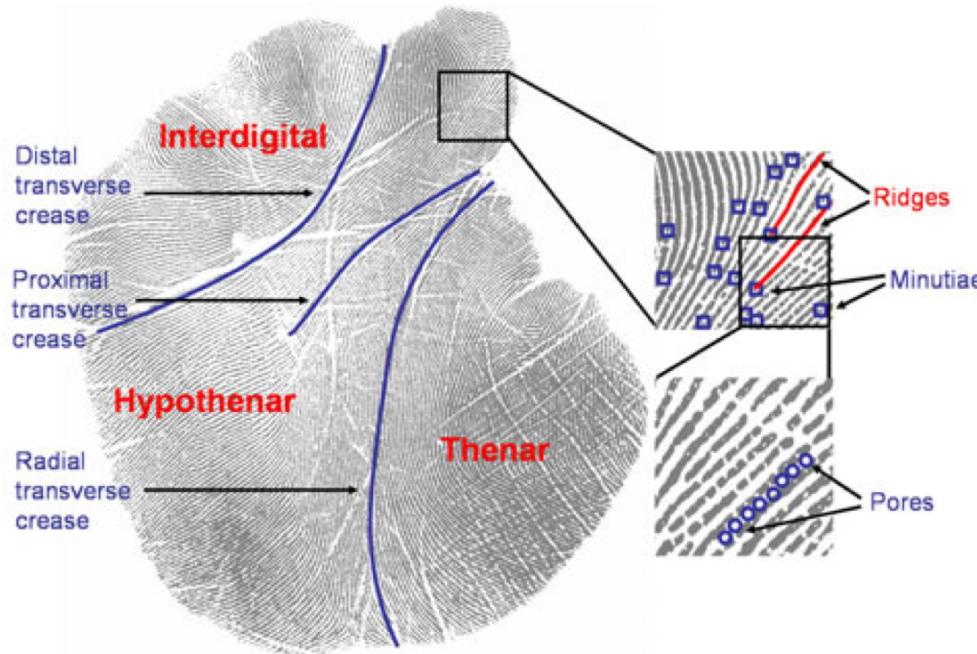
- ❖ Friction ridge patterns on the palm of the hand and the sole of the foot have also been claimed to be unique and permanent and thus can be used for personal identification
- ❖ Have fewer applications than fingerprints since it is not as convenient to capture them compared to fingerprints



Friction ridge patterns on palm and sole

Palmpoint and applications

- ❖ Different (special) applications: e.g. friction ridge skin protected inside flight boots tends to survive the trauma of a plane crash (and accompanying fire) better than fingers
- ❖ Further readings are required as homework



Outline

- ❖ **Introduction**
- ❖ **Fingerprint features**
 - **3 levels of features**
 - **Acquisition**
 - **Extraction**
- ❖ **Fingerprint matching**
- ❖ **Fingerprint synthesis**
- ❖ **Palmpoint and applications**
- ❖ **Summary**

Summary

- ❖ Fingerprint recognition is one of the most mature biometric technologies (over 100 years)
- ❖ Many new apps: e.g., researchers developed methods of identifying users of marijuana, cocaine and methadone from their fingerprint residues
- ❖ Widespread use of fingerprint (and other biometric) recognition systems has raised concerns about the fingerprint template's security and the user privacy
- ❖ 2nd part of this module will deal with this issue
- ❖ Further reading (optional):
 - Ctirad Sousedik, Christoph Busch: *Presentation attack detection methods for fingerprint recognition systems: a survey*, IET Biometrics, 3(4): 219-233, 2014

Q&A

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Question ?



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