Biometric Authentication

Lecture 7

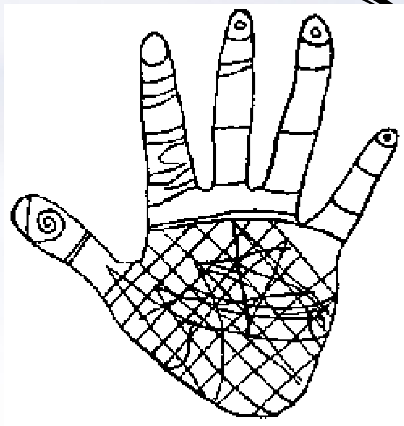
Traditional Uni-Modal
Fingerprint Identification

OUTLINE

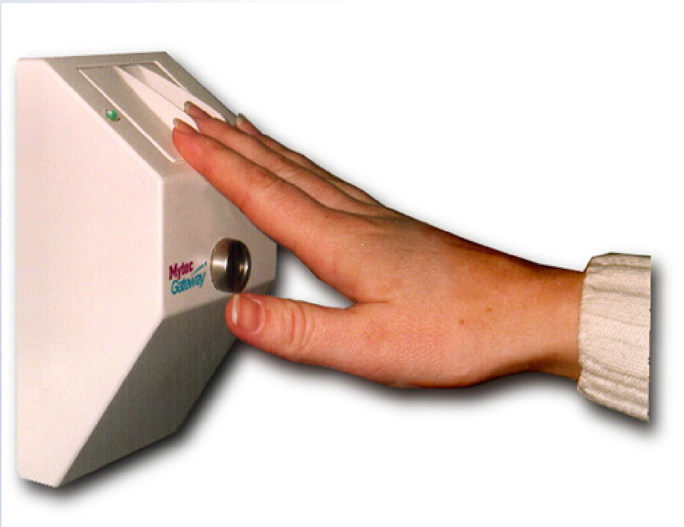
- Introduction
- System Overview
- Feature Extraction
- Classification & Matching

Fingerprint

Why Fingerprint?



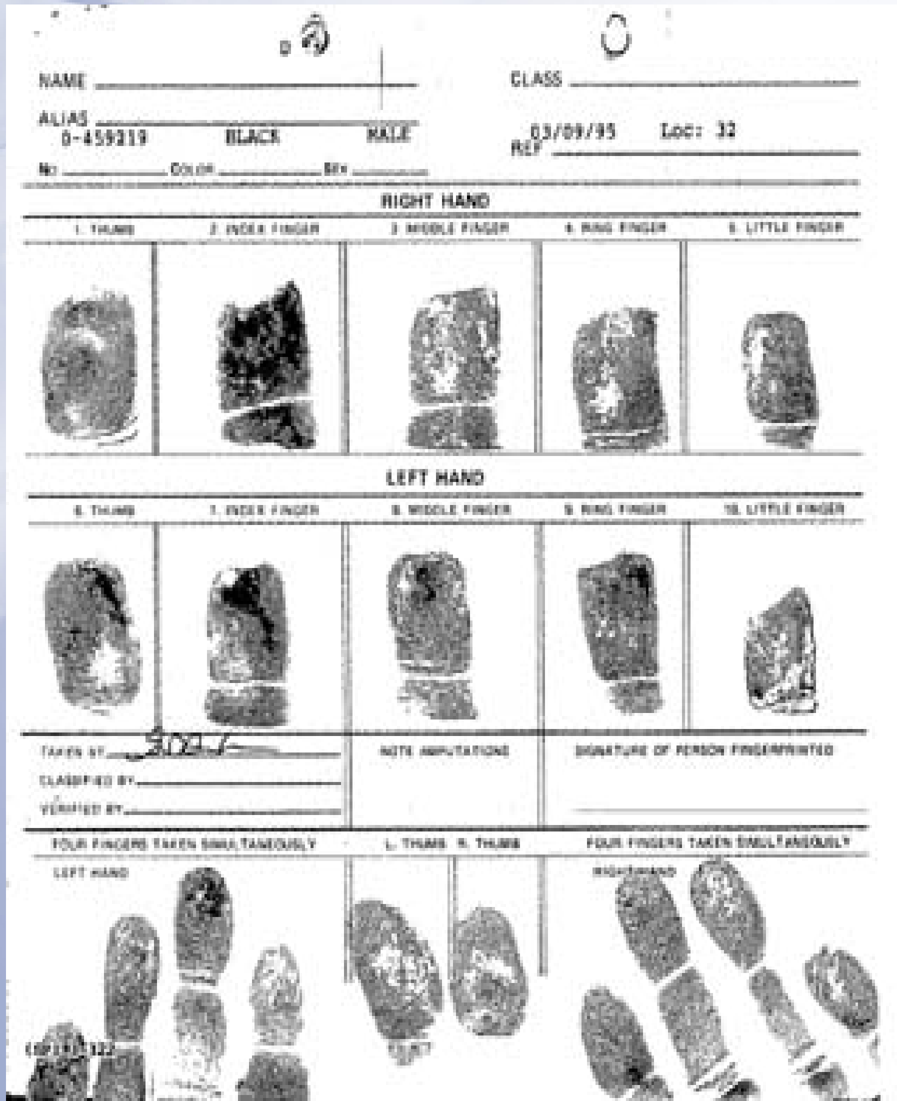
- ❑Fingerprint identification
  - ◆a trustworthy means of personal identification
  - ◆cannot be stolen, duplicated, shared
  - ◆other personal characteristics change but fingerprint do not
- ❑Best known biometric technology
- ❑Used as a method of identification for over 100 years
- ❑Huge databases are now available for instant searches



What is Fingerprint?

- Skin on the inside surface of our hands, fingers, feet and toes is ridged or covered with concentric raised patterns
- These ridges are called friction ridges
  - Serve the function of grippers so you can hold an object without slippage
- Many differences in the way friction ridges are patterned, broken and forked, which makes fingerprints unique
- Fingerprint characteristics
  - Graphical flow like ridges present in human fingers
  - Formation depends on the initial conditions of the embryonic development
  - They are believed to be unique to each person (and each finger); acceptable in courts of law

Fingerprint History

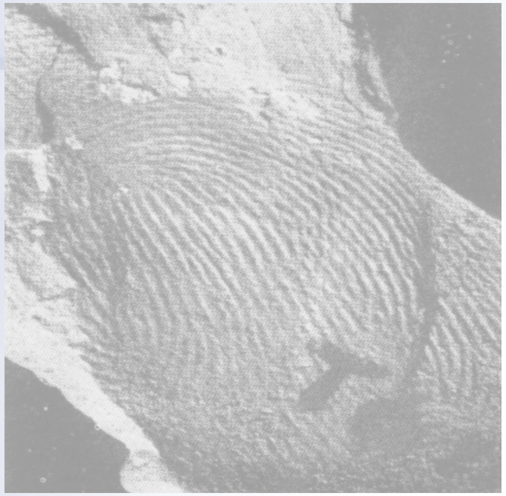


- ❑Around 1870, a French anthropologist devised a system to measure and record the dimensions of certain bony parts of the body
- ❑Measurement reduced to a formula and theoretically would only apply to one person and would not change during his/her adult life
- ❑Was generally accepted for thirty years until 1903 when twin brothers were sentenced to prisons

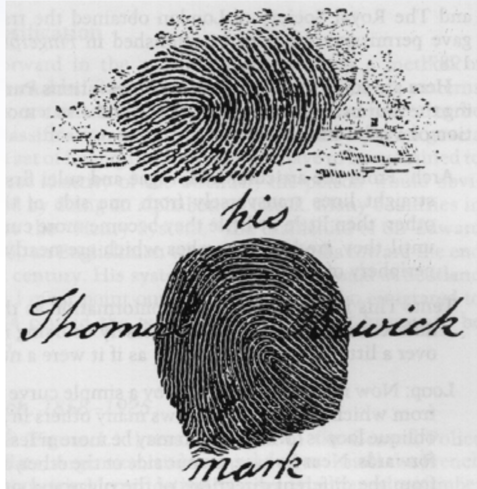
Fingerprint History (2)

- In 1902, First systematic use of fingerprint in the U.S. by the New York Civil Service Commission for testing.
- In 1924, an act of congress established the Identification Division of the FBI (Federal Bureau of Investigation).
- By 1946, the FBI had processed 100 million fingerprint cards in manually maintained files
- With increasing used for a range of non-criminal justice, traditionally manual fingerprint and record systems incapable of meeting today's needs for timely and accurate information
- Finally, automated fingerprint identification system was setup.

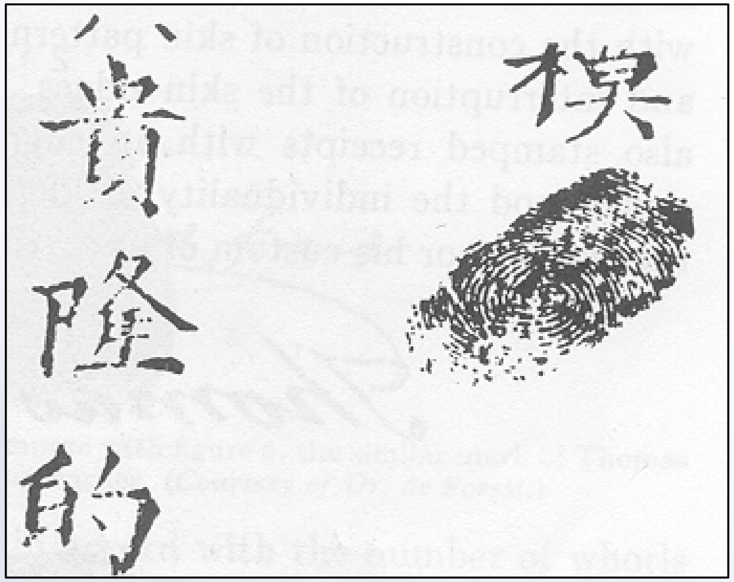
Fingerprint History (3)



Fingerprint on Palestinian lamp (400 A.D.)

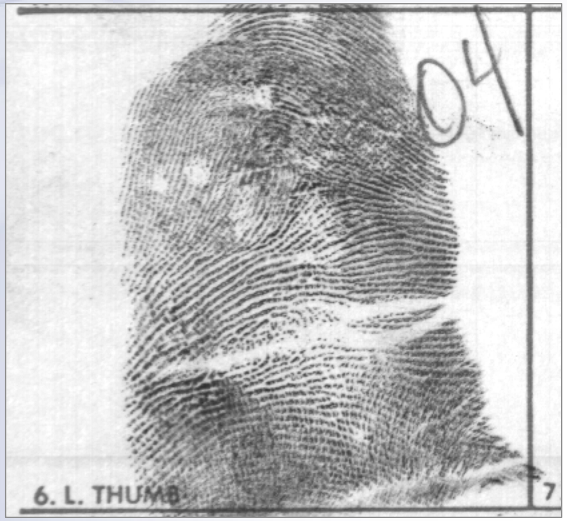


Bewick’s trademark



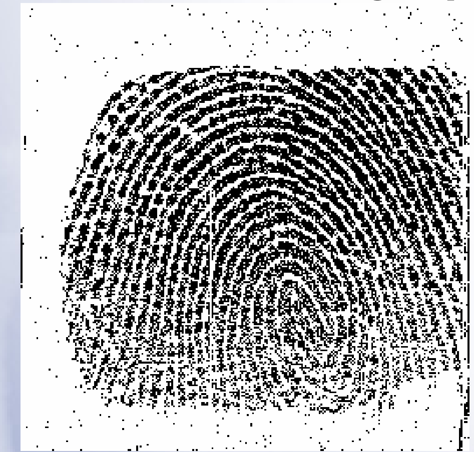
A Chinese deed of sale (1839) signed with a fingerprint

Fingerprint Images:
Different Resolution



A rolled inked fingerprint

Digital Biometrics sensor (508x480)

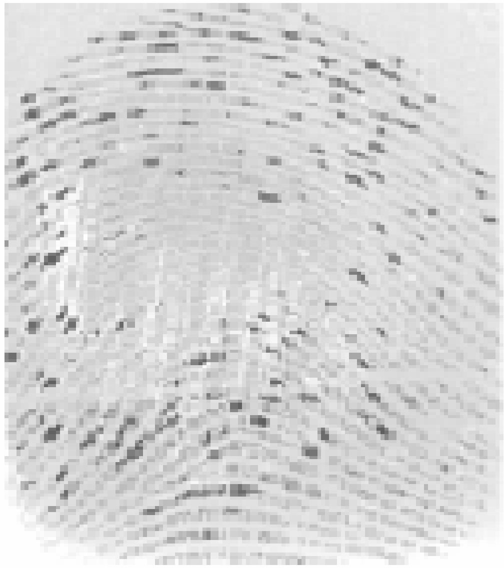


Fidelica sensor (256x256)

Veridicom sensor (300x300)

Fingerprint Images

(a) High quality



(b) Poor quality

Different Quality

Inked image

on-line image

Different Capture

System Overview

Fingerprint

Acquisition

Pre-processing

Feature Extraction

Matching

Matching Score

Enrollment stages

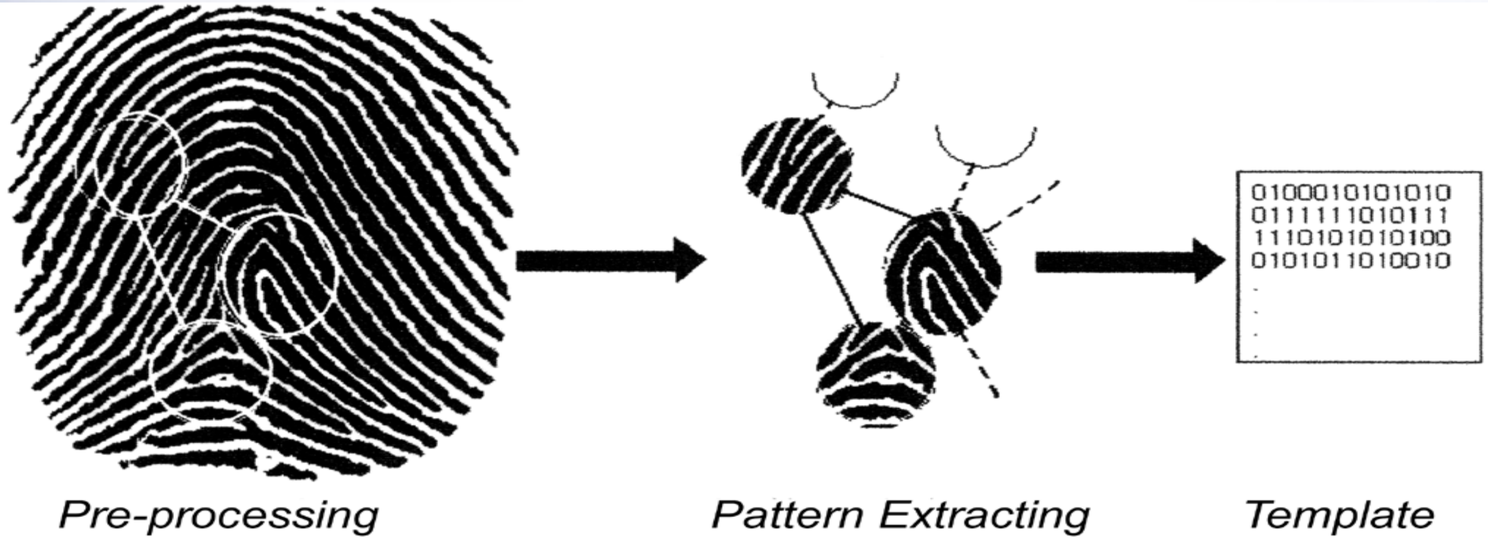
- Image acquisition : Inked based scanning & Live based scanning
- Fingerprint extraction : identifying and specifying small details found in finger images
- Storing : recording the result of extraction on the database

Authentication stages

- Capture
- Extraction
  - Preprocessing
  - Detect minutia
- System search for similarities (matching process)

Acceptable score

Example: On-Line Verification



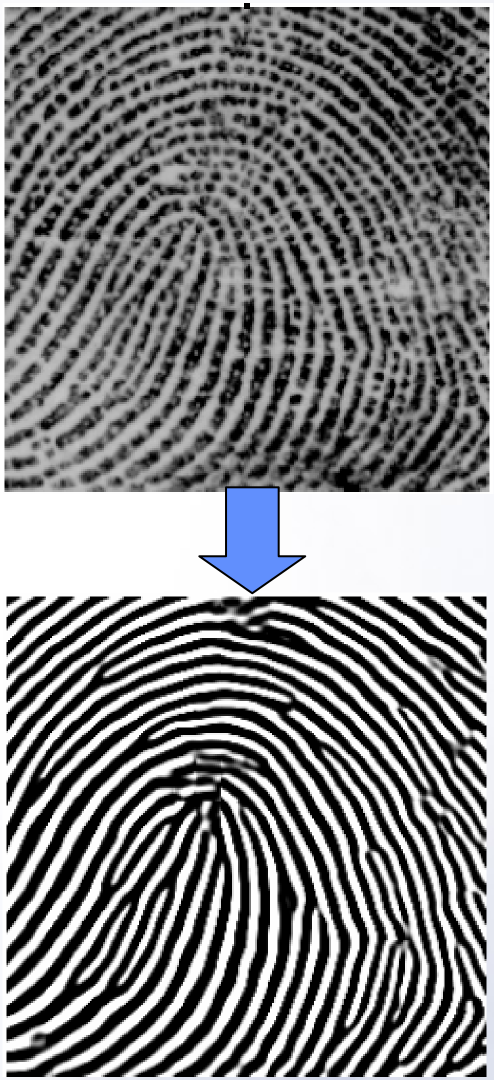
Source: Precise Biometrics

System Overview: Acquisition

- Captured fingerprint by using a fingerprint sensor
- Sensor can be optical, capacitive, pressure, thermal, or ultrasound
- Digital image consisting of 8-bit (256 gray level)
- User-friendly
- Fingerprint identification algorithm complicated

System Overview: Pre-processing

- ◆Important stage before feature extraction
- ◆Poor quality of fingerprint images due to noise
- ◆Enhancement, segmentation and thinning



Enhancement

- ◆Noise removal
- ◆Enhance quality of fingerprint image
- ◆Low-pass filter, FFT-based technique, oriented filters

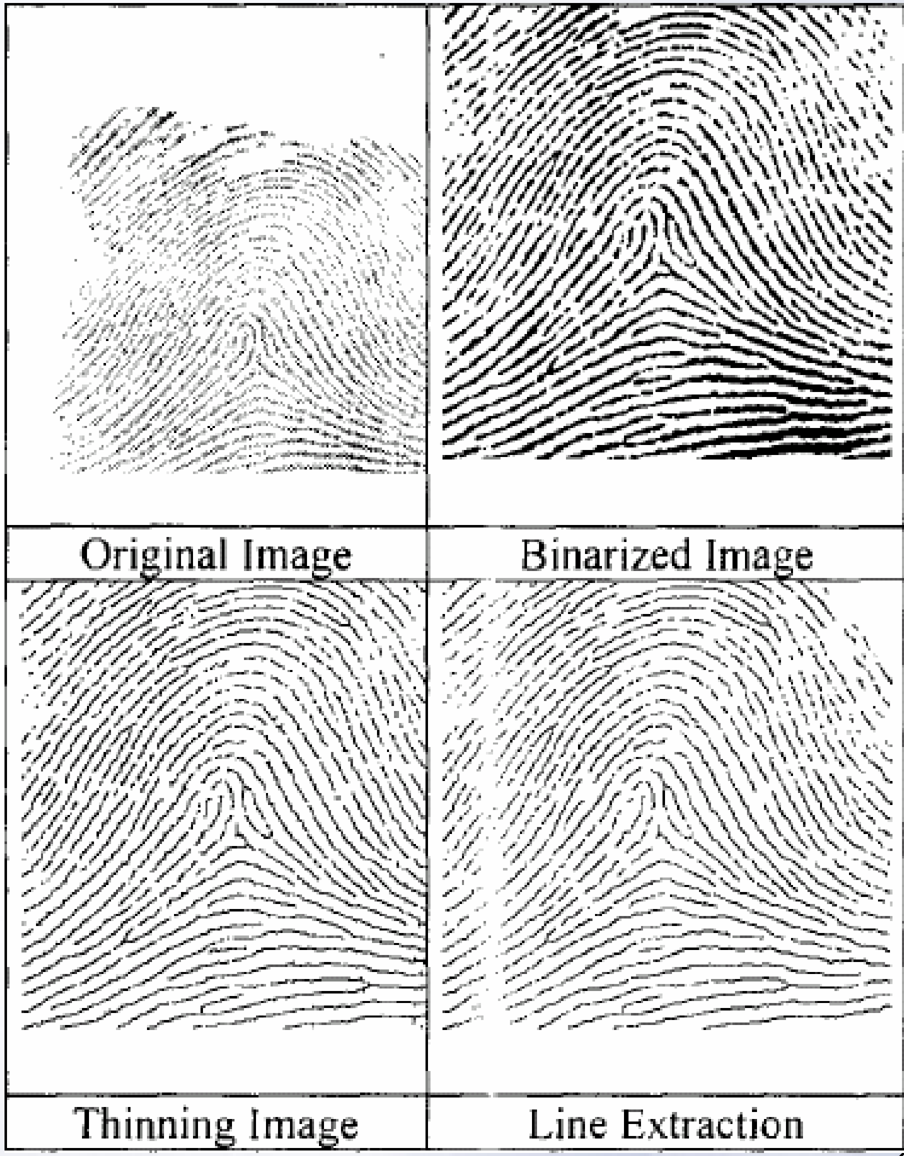
System Overview: Pre-processing

Segmentation

- Decomposition to foreground & background
- Foreground – fingertip image
- Background – Noisy area outside fingertip

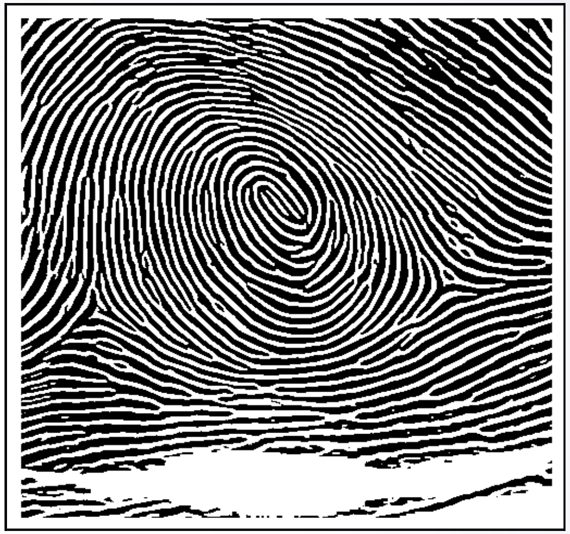
Binarization & Thinning

- Binarization by a thresholding operation
- Thinning to reduce the width of ride to a single pixel

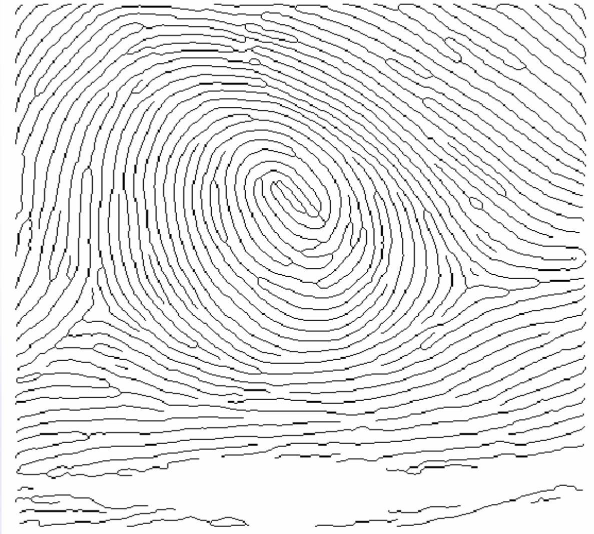


Fingerprint Preprocessing

Original image



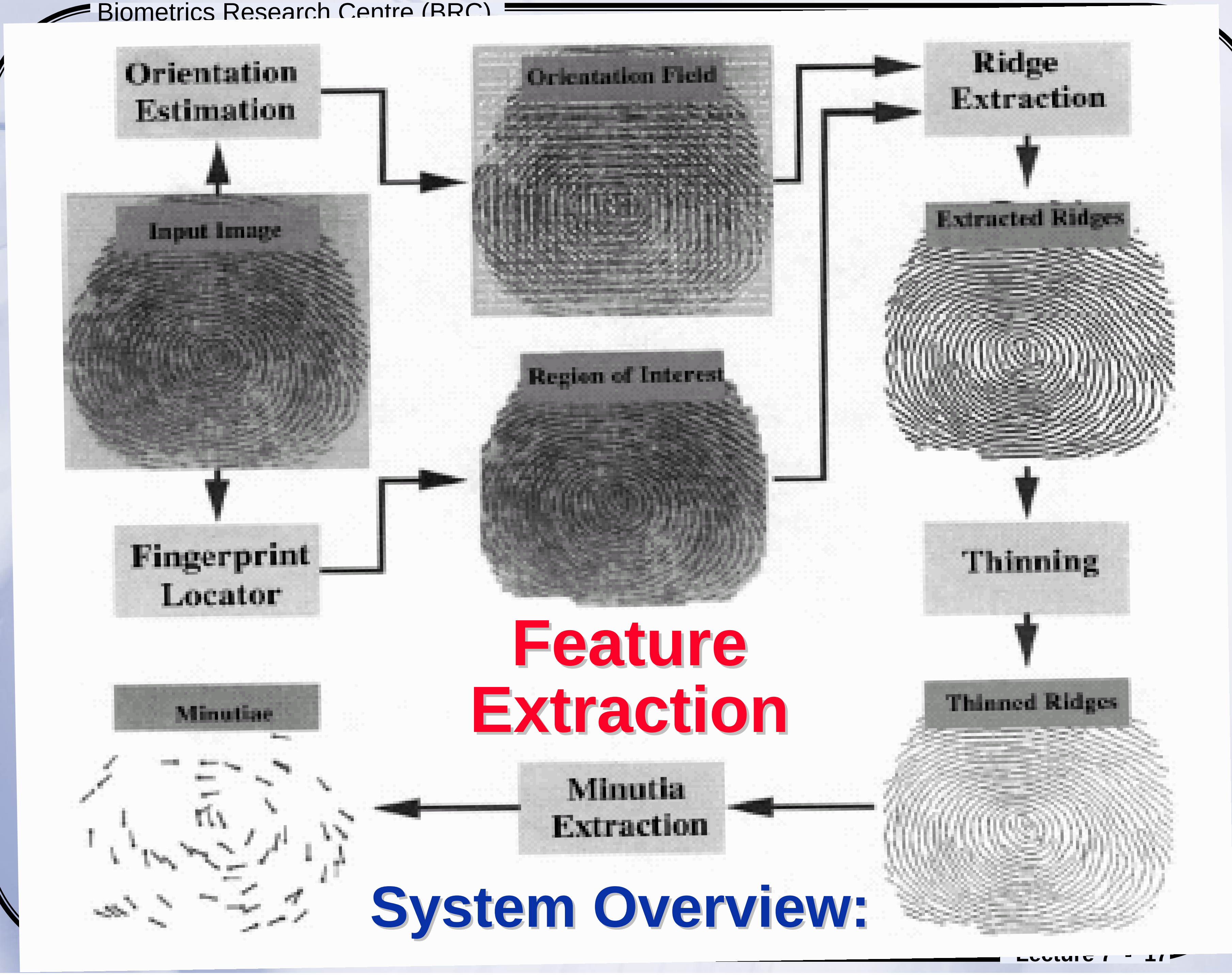
Binary image



Thinning image

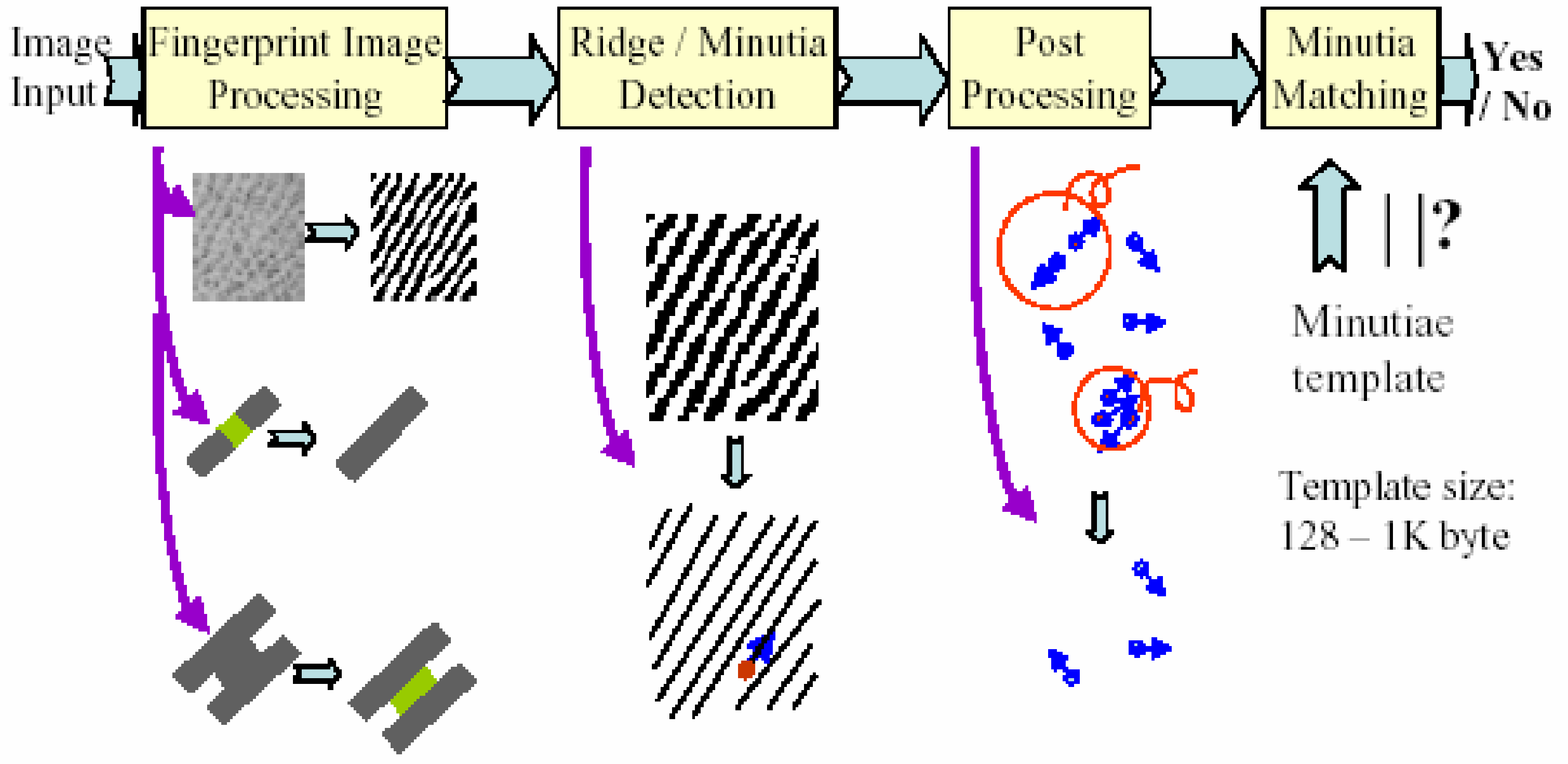
System Overview:

Feature Extraction



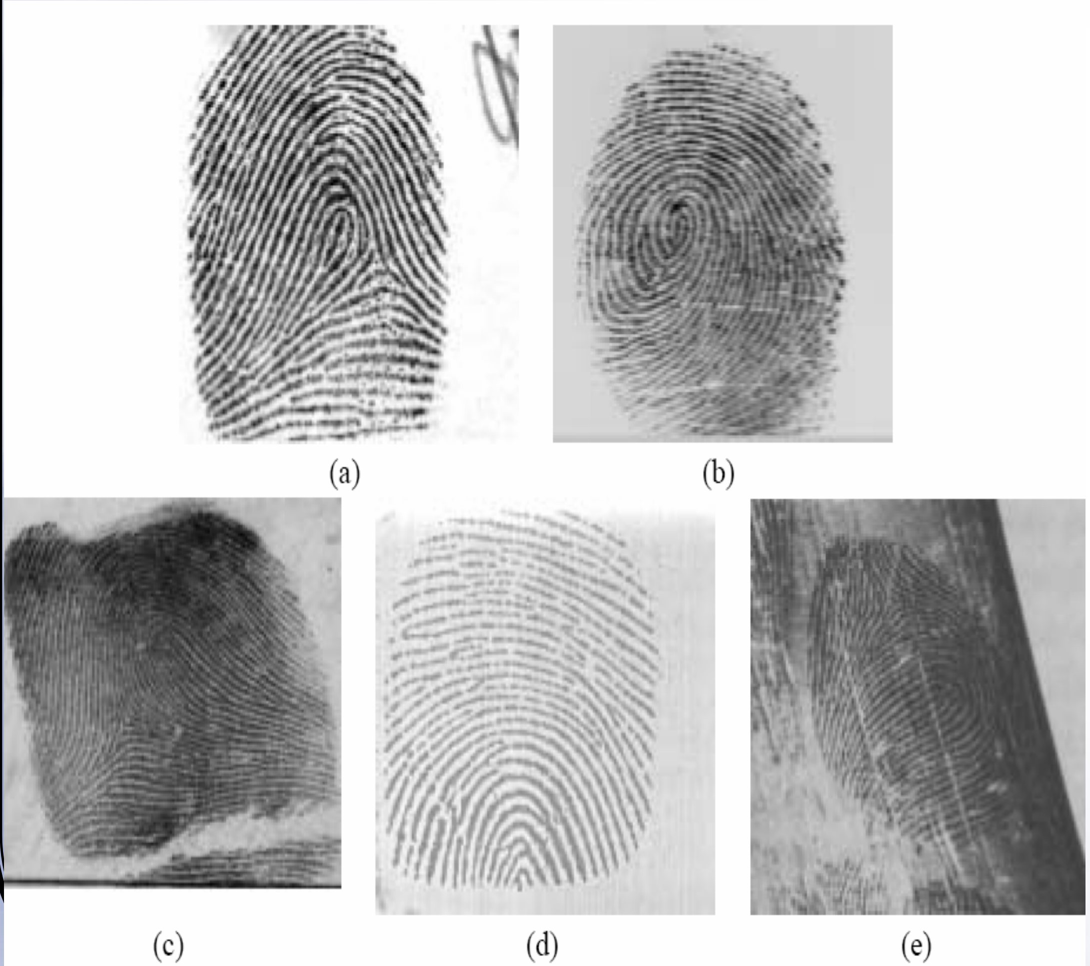
System Overview: Feature Matching

- Align the test and reference pattern
- Count the number of minutia pairs
- Determine the matching score
- Based on certain threshold to determine ‘match’ or not



Fingerprint Sensing

- Two primary methods: inked (off-line) and live scan (ink-less)

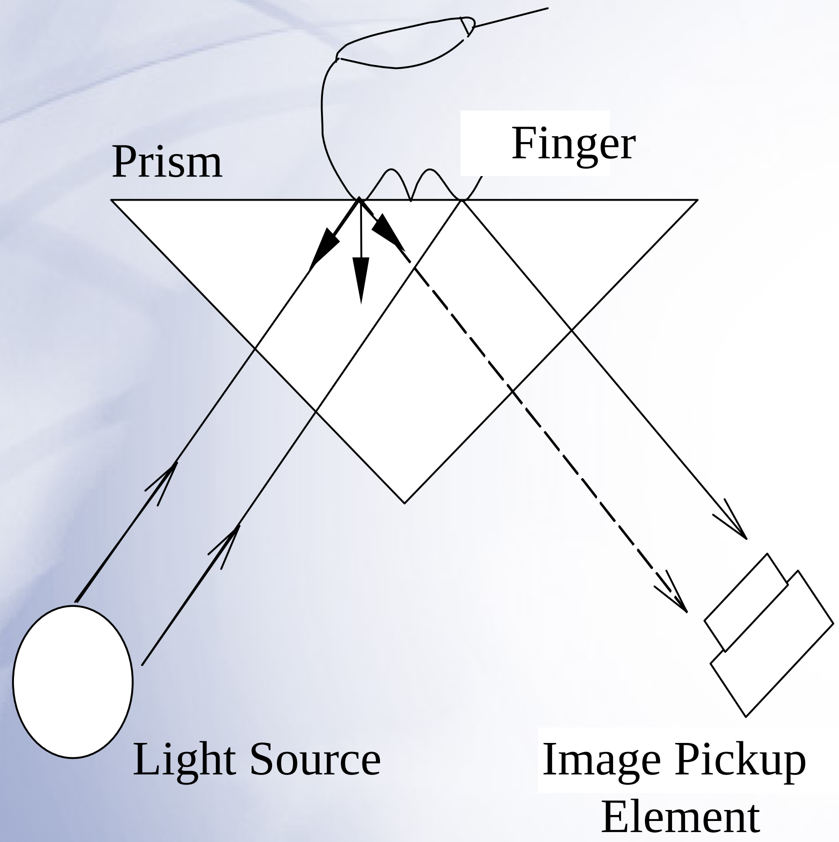


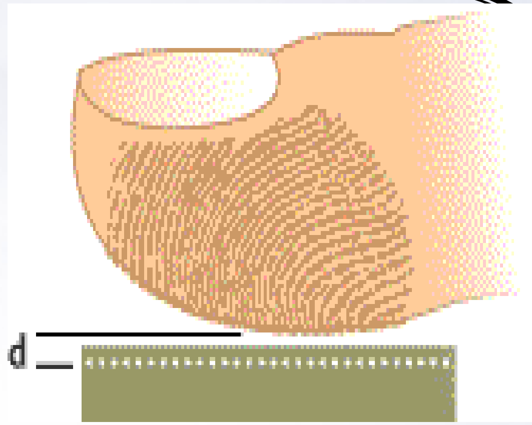
(a) an inked fingerprint image;
(b) a livescan fingerprint imaged from a optical sensor;
(c) rolled fingerprints are images depicting nail-to-nail area of a finger;
(d) fingerprints captured using solid state sensors;
(e) a latent fingerprint from a scene of crime.

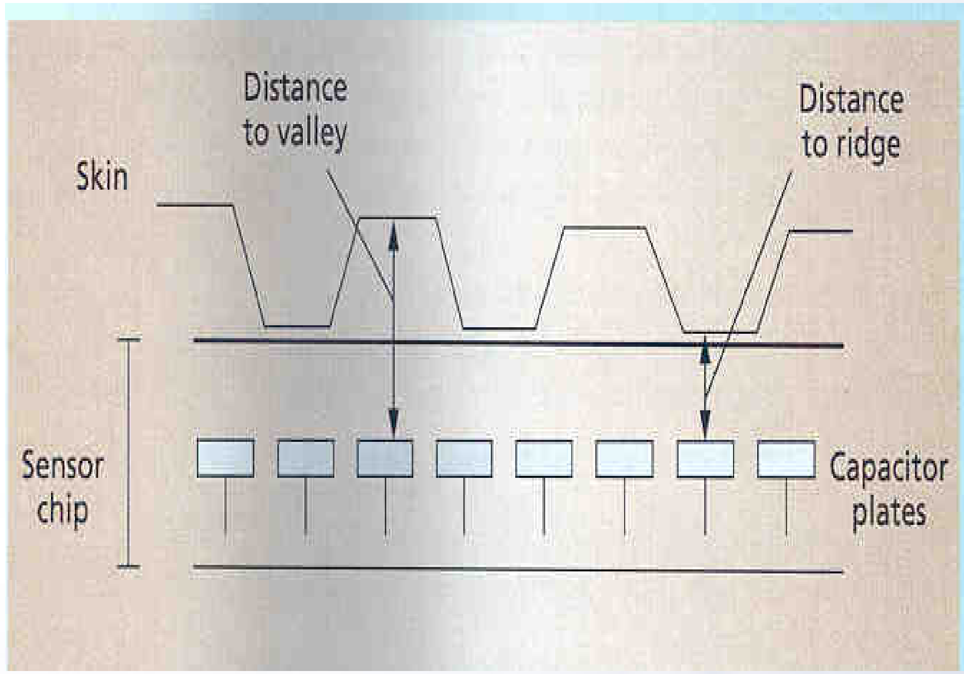
Fingerprint Sensing

- An inked fingerprint image is typically acquired by a trained professional obtains an impression of an inked finger on a paper and the impression is then scanned using a flat bed document scanner.
- The live scan fingerprint is a collective term for a fingerprint image directly obtained from the finger without the intermediate step of getting an impression on a paper.
- The most popular live-scan fingerprint technology is based on optical frustrated total internal reflection (FTIR) concept.
- When a finger is placed on one side of a glass platen (prism), ridges of the finger a in contact with the platen, while the valleys of the finger are not in contact with the platen.

Fingerprint Input Devices







CCD Device

VLSI Device

Leading methods in finger scan technologies:
Optical, Silicon and Ultrasound, Thermal, etc.

Optical Technology

- User places finger on platen (glass)
- Camera acquired the image, where digitized ridges and valleys appear as black, gray and white lines
- Underlying software assesses fingerprint quality
- Generates template for enrollment or verification

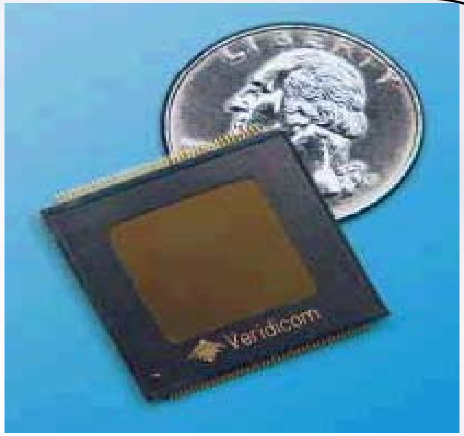
Strengths

- ❑ Proven reliable over time
- ❑ Resistant to electrostatic discharge
- ❑ Fairly inexpensive
- ❑ Can provide resolutions up to 500 dpi (high-quality fingerprint images)

Weaknesses

- ❑ Platen size must have sufficient surface area and depth to capture quality images
- ❑ Tendency to show latent prints as actual fingerprints
- ❑ Susceptibility to fake fingers

Silicon Technology



- Silicon chip is used as the platen
- Produces better image quality with less surface area than optical devices

Strengths

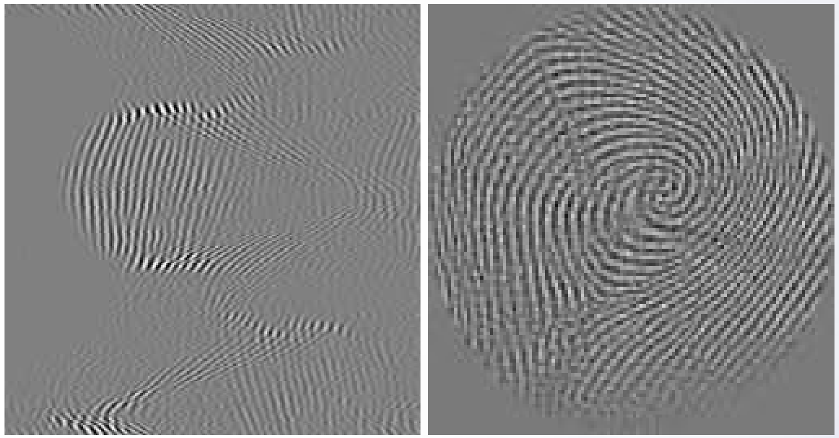
- ❑ High image quality (approaching that of the “better” optical devices
- ❑ Modest size requirements (allowing technology to be integrated into small, lower power devices
- ❑ Potentially lower cost (large number of platens can be manufactured from a single wafer)

Weaknesses

- ❑ Durability is subject to question
- ❑ Some silicon technology have been susceptible to electrostatic damage
- ❑ Performance in challenging conditions is unproven

Ultrasound Technology

- Least frequently used of the three
- Considered the most accurate
- Ultrasonic beam is scanned across the fingerprint surface
- Echo signal is captured at the receiver
- Measures range, thus ridge depth



Impulse Response   Reconstruction

Strengths

- ❑ High quality fingerprint images
- ❑ Capable of penetrating dirt and residue

Weaknesses

- ❑ Larger acquisition device due to the machinery involved in ultrasound imaging

Fingerprint Sensors

Fingerprint

One Line Sensor

Fingerprint Representation

- Several representations have been used to assess fingerprint similarity.
- Fingerprint representations can be broadly categorized into two types: global and local. Global representation is an overall attribute of the finger and a single representation is valid for the entire fingerprint and is typically determined by an examination of the entire finger.
- A local representation consists of several components, each component typically derived from a spatially restricted region of the fingerprint.
- Typically, generic representations are used for fingerprint indexing and local representations are used for fingerprint matching.

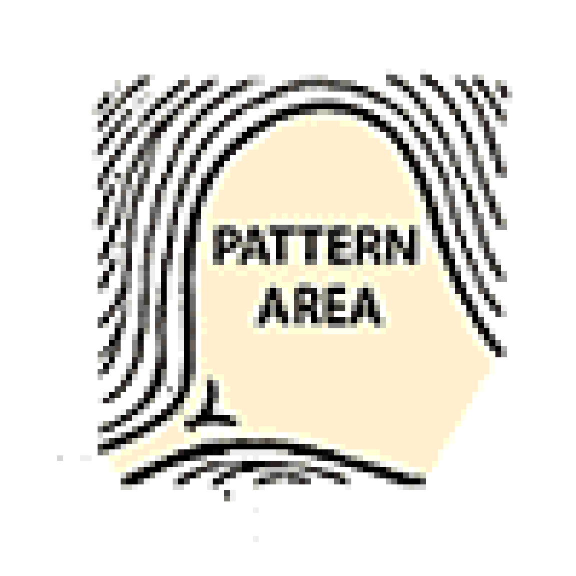
Global Feature Characteristics

A fingerprint is a pattern of flowing line structure consisting of ridges and valleys OR curving line structures (ridges) and skin with a higher profile than its surroundings (valleys)

- Pattern Area
- Core Point
- Type Lines
- Delta
- Ridge Count
- Basic Ridge Patterns
  - Loop
  - Arch
  - Whorl

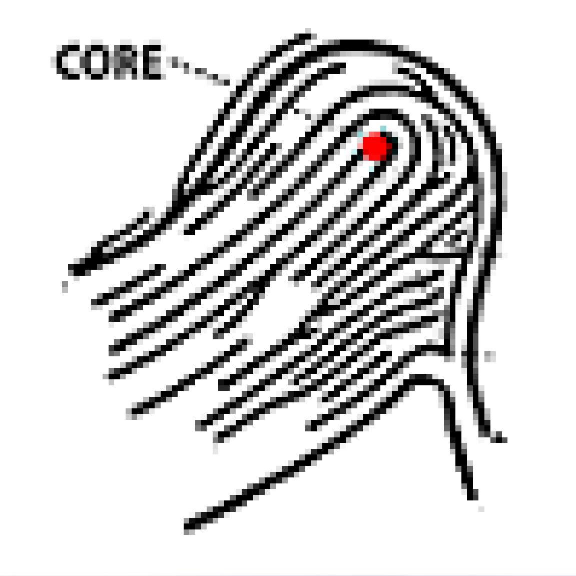
Pattern Area

- Area of the fingerprint that contains all the global features
- Can be read and classified based on the information in the pattern area



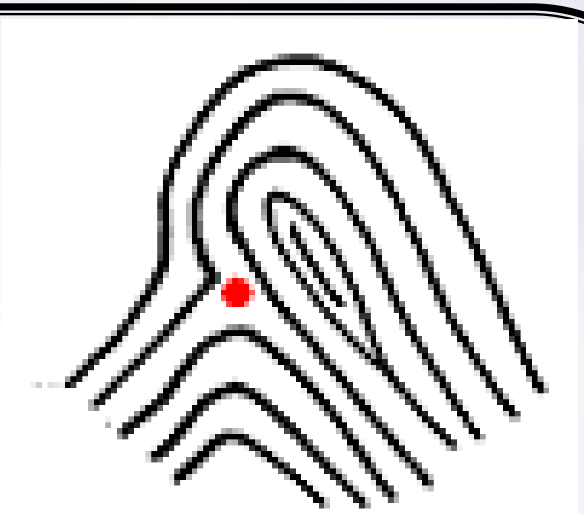
Core Point

- Located at the approximate center of the finger impression
- Used as a referenced point for reading and classifying the print



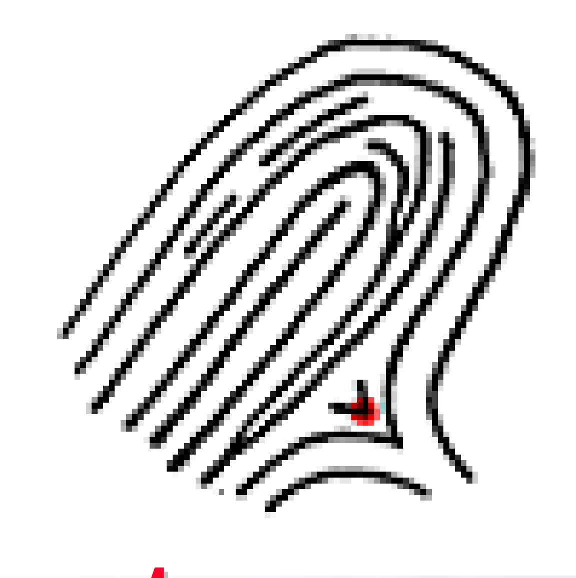
Type Lines

- Two innermost ridges that start parallel, diverge, and surround or tend to surround the pattern area



Delta

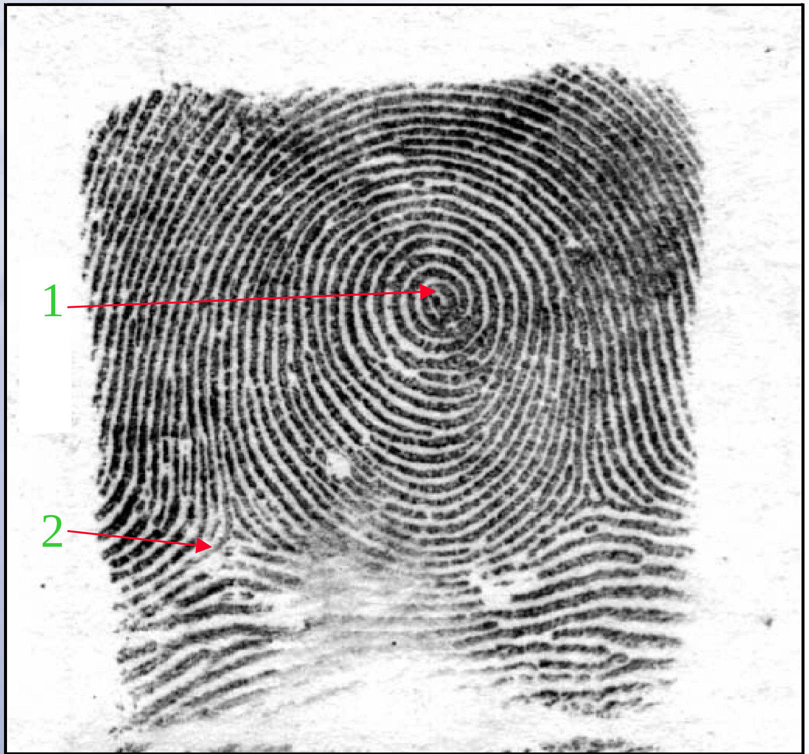
- It is a definite fixed point used to facilitate ridge counting and tracing

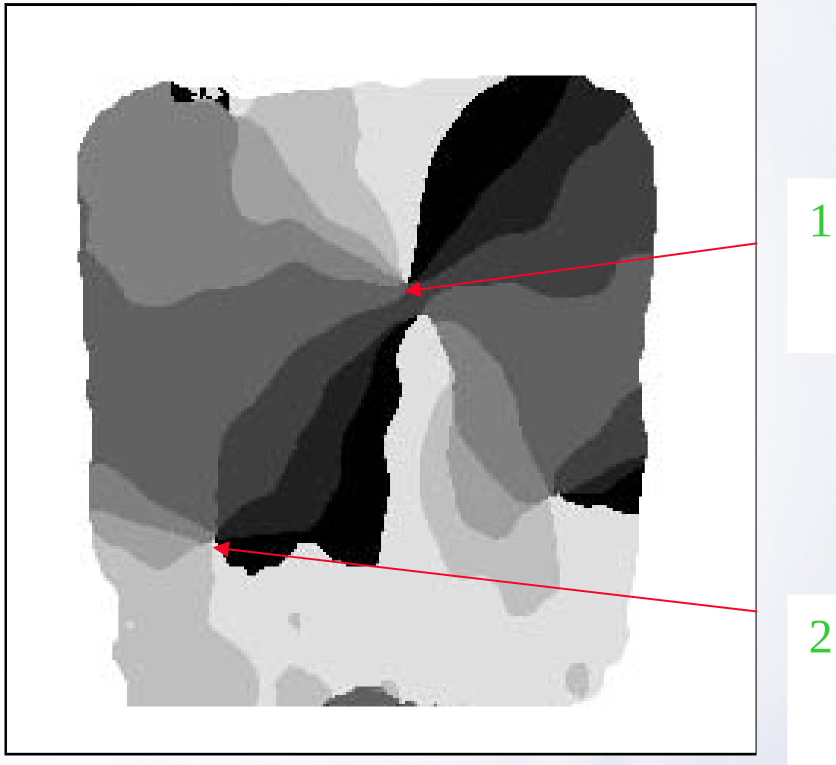


Ridge Count

- The number of ridges between the delta and the core

Singular Points (Core/Delta) Extraction





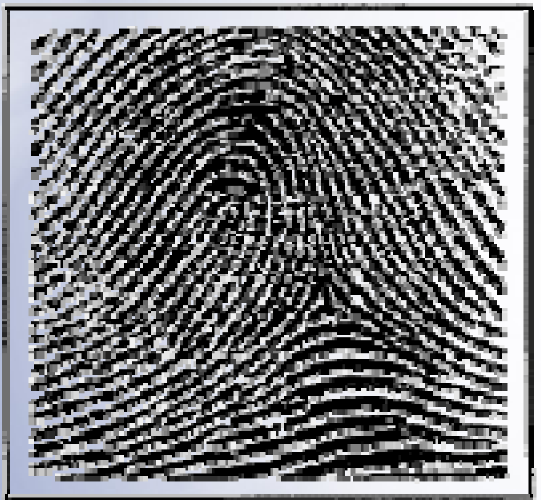
Original image Direction image

(1: Core point; 2: Delta point)

Basic Ridge Patterns

- Arch – ridges enter from one side, rise to a ridge in the center and exit out the opposite side (has no delta)

ARCHES



LOOP

- Loop – one or more ridges make a loop and then exit the same side they entered (has only one delta)

WHORL

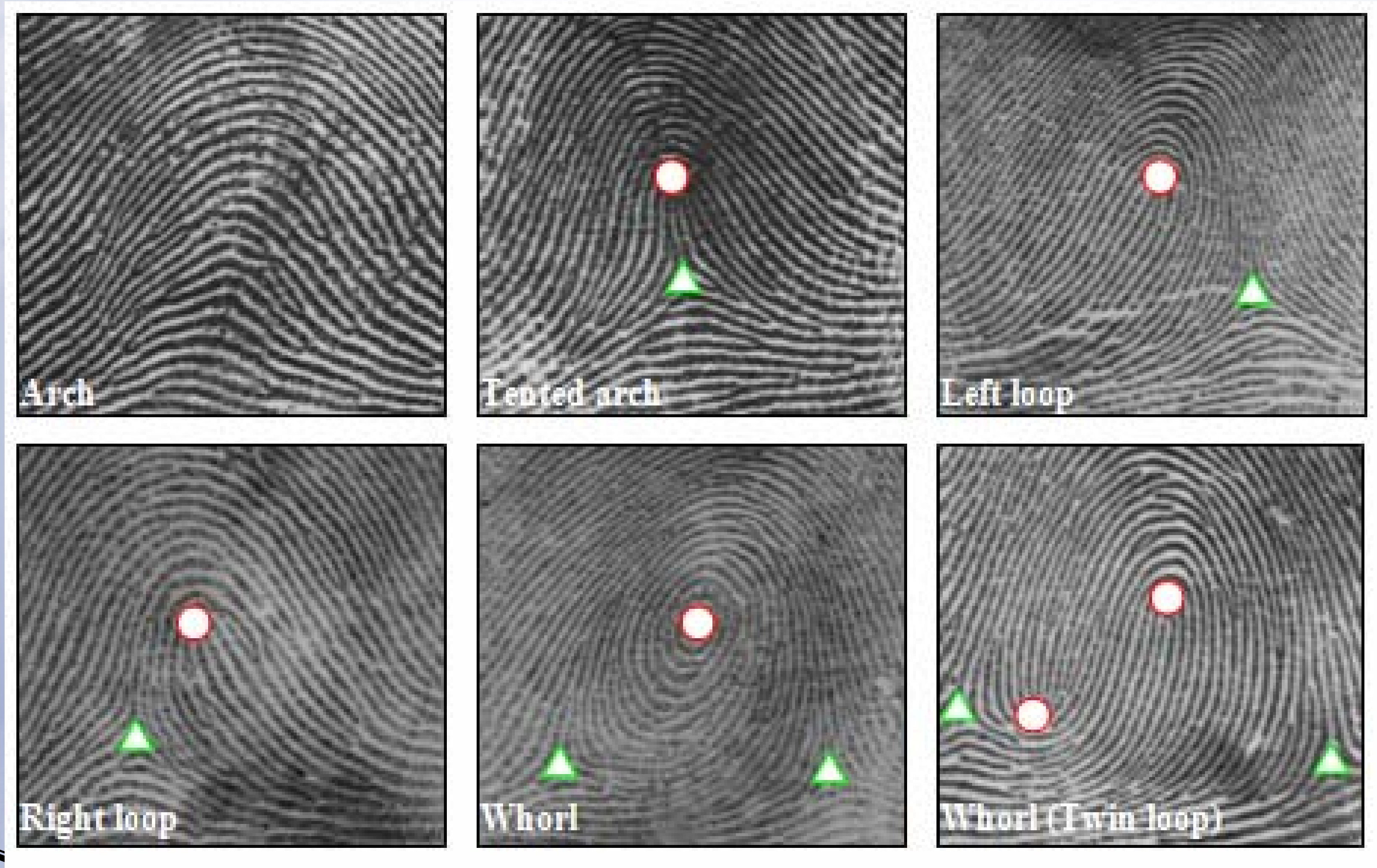
- Whorl – at least one ridge makes a 360 degree circle in the center of the print (has two deltas)

Fingerprint Classification

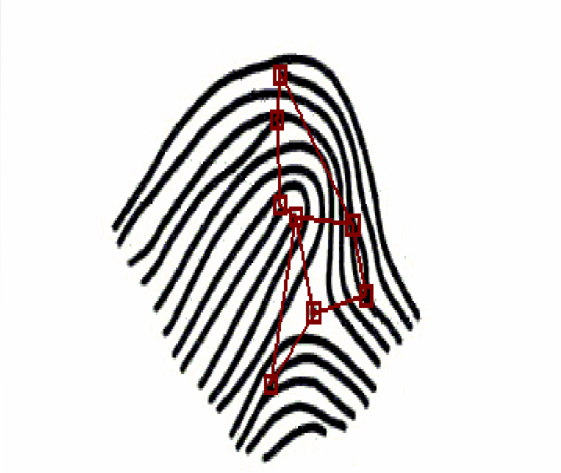
- Fingers can also be distinguished based on features such as ridge thickness, ridge separation, or ridge depths.
- Some examples of global representation include information about locations of critical points (e.g., core and delta) in a fingerprint.
- Core-delta ridge count feature, sometimes simply referred to as the ridge count, measures the number of ridges between core and delta points on a finger.
- All these features measure an overall property of a finger and we will refer to these similarities as global or generic features.

Fingerprint Classification

- One of the significant global features used for fingerprints is its class or type. The overall fingerprint pattern is typically categorized as six major classes



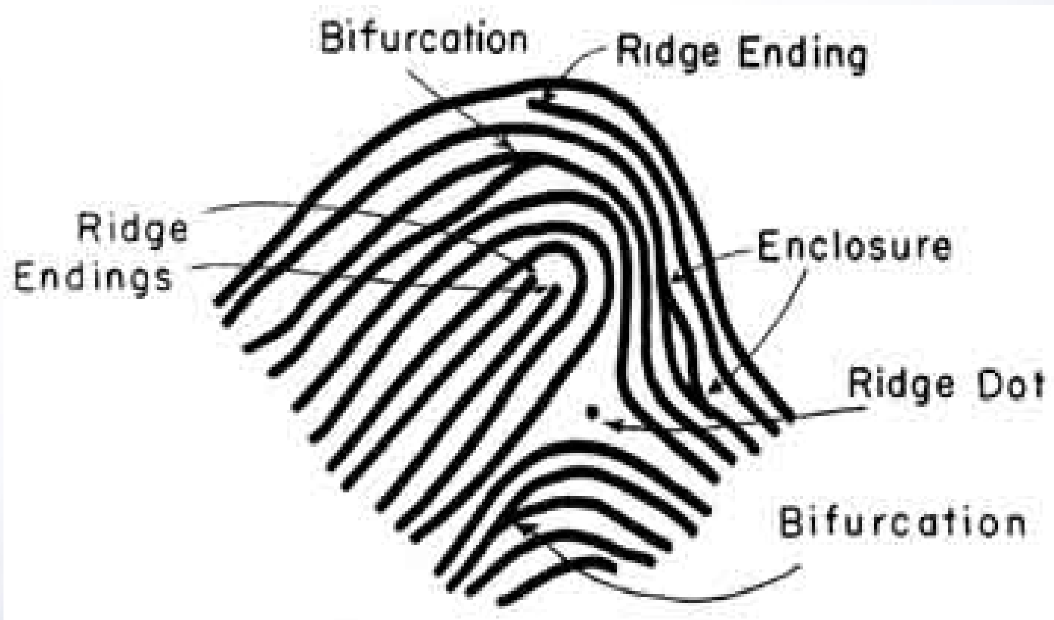
Local Representation



- Major representations of the local information in fingerprints are based on finger ridges, pores on the ridges, or salient features derived from the ridges.
- The most widely used local features are based on minute details (*minutiae*) of the ridges. It forms a valid representation of the fingerprint.
- This representation is compact, and captures a significant component of individual information in fingerprints.
- Compared to other representations, minutiae extraction is relatively more robust to various sources of fingerprint degradation.

Local Feature Characteristics

- Known as minutia points which ridges end, fork and change
- Tiny, unique characteristics of fingerprint ridges that are used for positive identification
- Possible for one or more individuals to have identical global features but still have different and unique fingerprints because of the minutia points
  - Types
    - Ridge ending
    - Ridge bifurcation
    - Ridge divergence
    - Dot or Island
    - Enclosure
    - Short Ridge

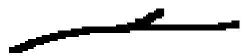
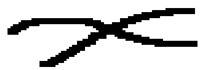
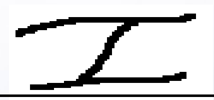


How to Select Ridge Features?

- A fingerprint is a smoothly flowing pattern of alternating valleys and ridges, the ridges and valleys being parallel in most regions.
- Several permanent and semi-permanent features such as scars, cuts, bruises, cracks, and calluses, are also present in a fingerprint.
- Use some *invariant* representation (features) from the fingerprints, for example:
  - the features which over a lifetime will continue to remain relatively unaltered irrespective of the cuts and bruises,
  - the orientation of the finger placement with respect to the medium of the capture,
  - occlusion of a small part of the finger,
  - the imaging technology used to acquire the fingerprint from the finger,
  - or the elastic distortion of the finger during the acquisition of the print.

Fingerprint

Different Minutiae

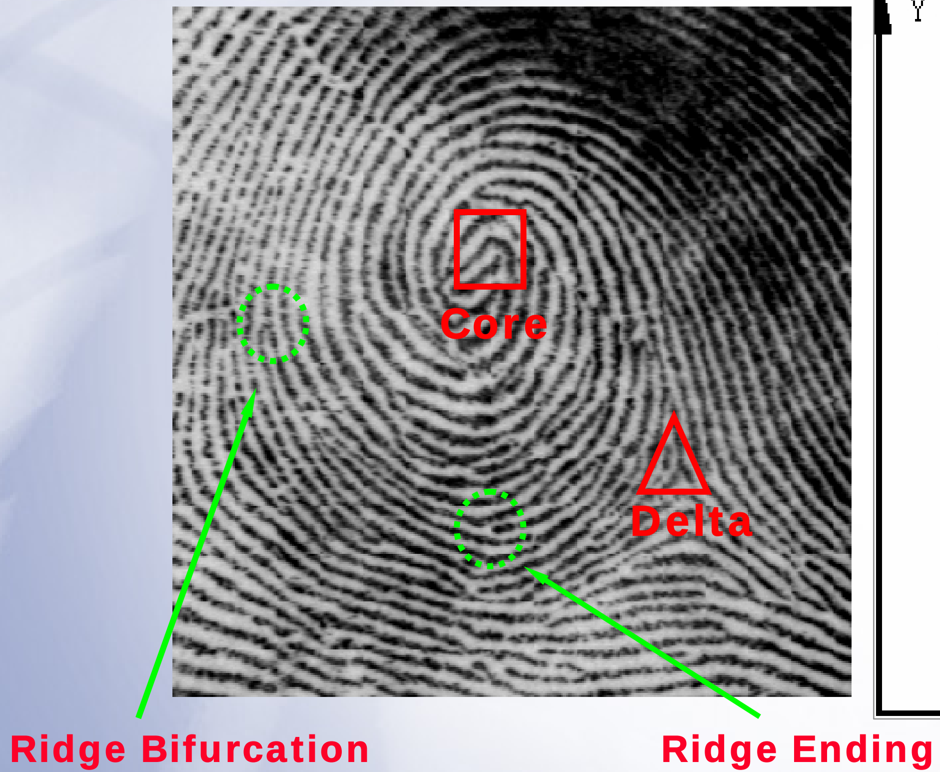
Primitive Minutiae	Dot	
	Ridge Ending	
	Bifurcation	
Compound Minutiae	Island	
	Spur	
	Crossover	
	Bridge	
	Short Ridge	

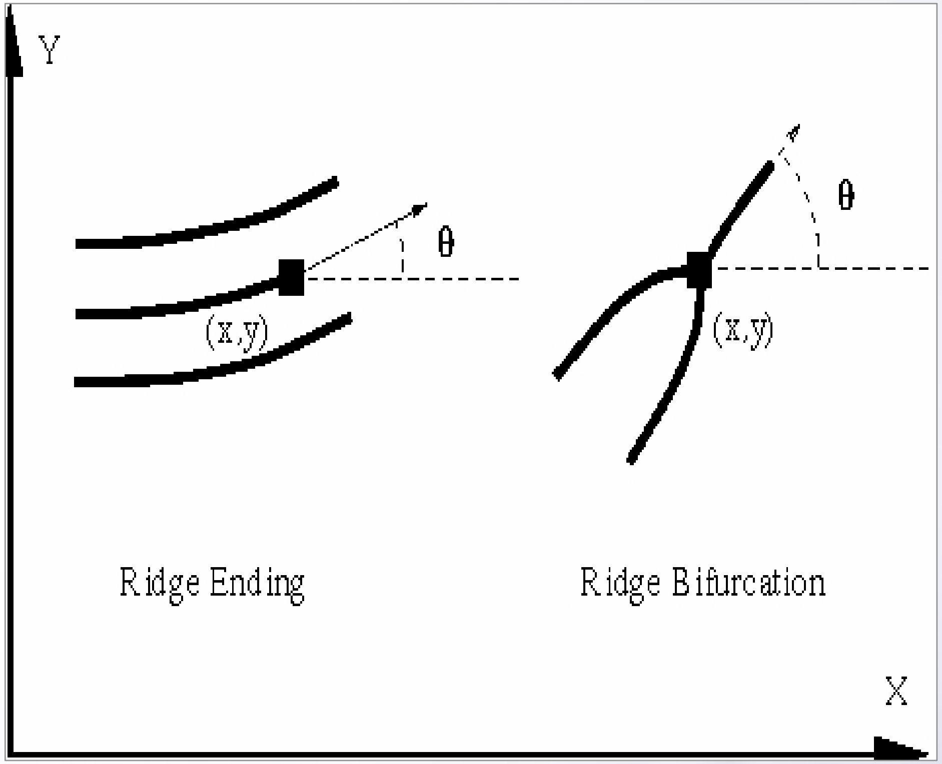
Local Representation

- Most types of minute details in fingerprint images are not stable and can not be reliably identified by automatic image processing methods.
- Therefore, in automatic fingerprint matching, only the two most prominent types of minute details are used for their stability and robustness: (i) *ridge ending* and (ii) *ridge bifurcation*.
- In addition, since various data acquisition conditions such as impression pressure can easily change one type of minutiae into the other, typical minutiae based representations do not make any distinction between these two types of features and are collectively referred to as minutiae.

Feature Representation

- Local ridge characteristics (minutiae): ridge ending and ridge bifurcation.





❑ Typically, in a live-scan fingerprint image of good quality, there are about 50-100 minutiae

Characteristics of Minutia Points

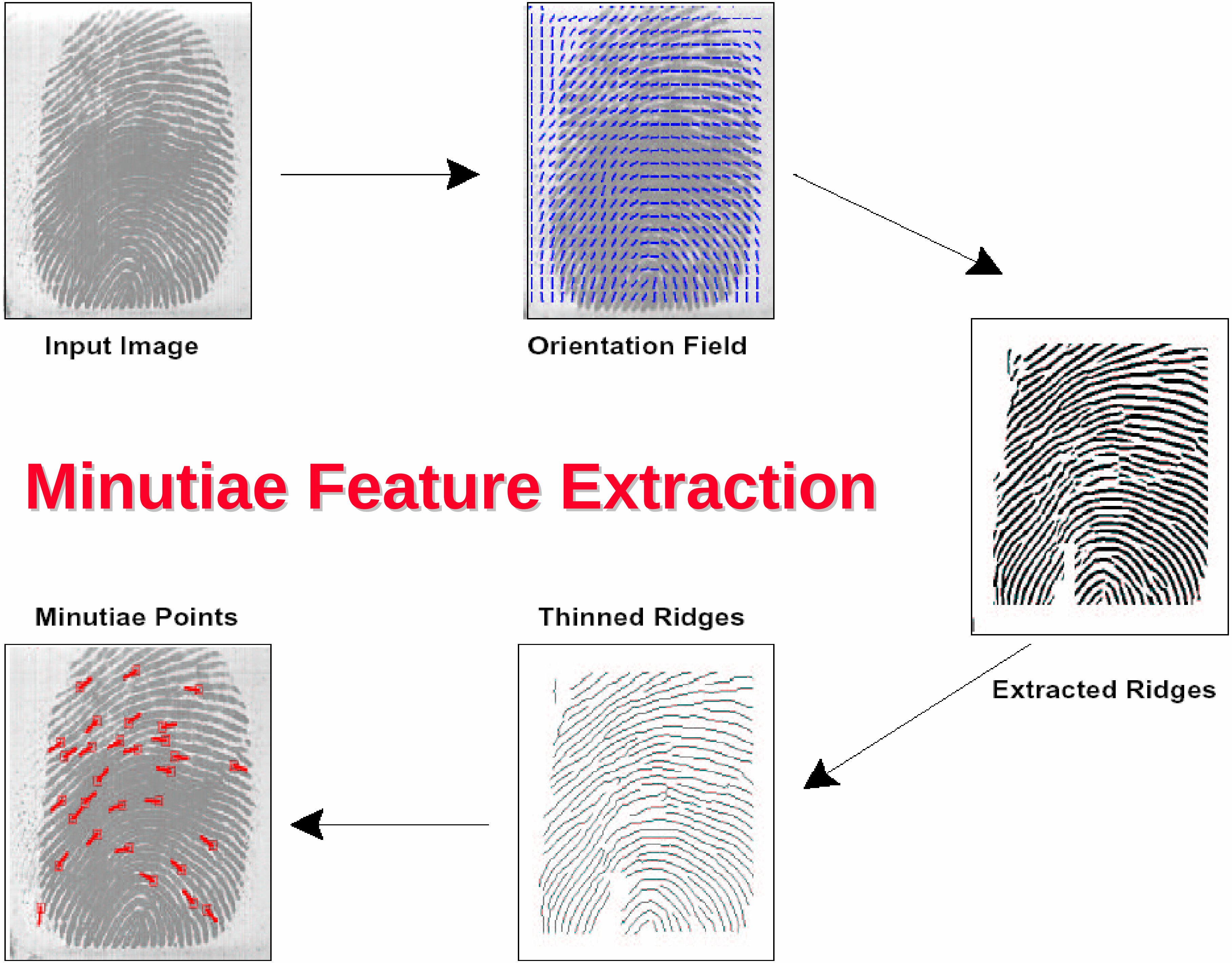
Fingerprint ridges are not continuous straight ridges - they are broken, forked, changed directionally or interrupted – It is necessary to use Minutia Points

- Orientation – the direction of the minutia point
- Spatial frequency – how far apart the ridges are in the neighborhood of the minutia point
- Curvature – refers to the rate of change of ridge orientation
- Position – refers to its x, y, location, either in an absolute sense or relative to fixed points like the delta and core points

Minutiae Feature Extraction

- It consists mainly of three stages:
  - (i) orientation field estimation,
  - (ii) ridge extraction,
  - (iii) minutiae extraction and postprocessing.
- First, for an input image, the local ridge orientation is estimated and the Region Of Interest (ROI) is located.
- Then, ridges are extracted from the input image, refined to get rid of the small speckles and holes, and thinned to obtain 8-connected single pixel wide ridges.
- Finally, minutiae are extracted from the thinned ridges and refined using some heuristics.

Minutiae Feature Extraction



Fingerprint Matching

- Given two (test and template) representations, the matching module determines whether the prints are impressions of the same finger.
- The matching phase typically defines a metric of the similarity between two fingerprint representations.
- The matching stage also defines a threshold to decide whether a given pair of representations belong to the same finger (mated pair) or not.
- Also, we assume that the test and template fingerprints depict the same portion of the finger and both are aligned with each other, i.e. align (or register) the fingerprints (or their representations) before deciding whether the prints are mated pairs.

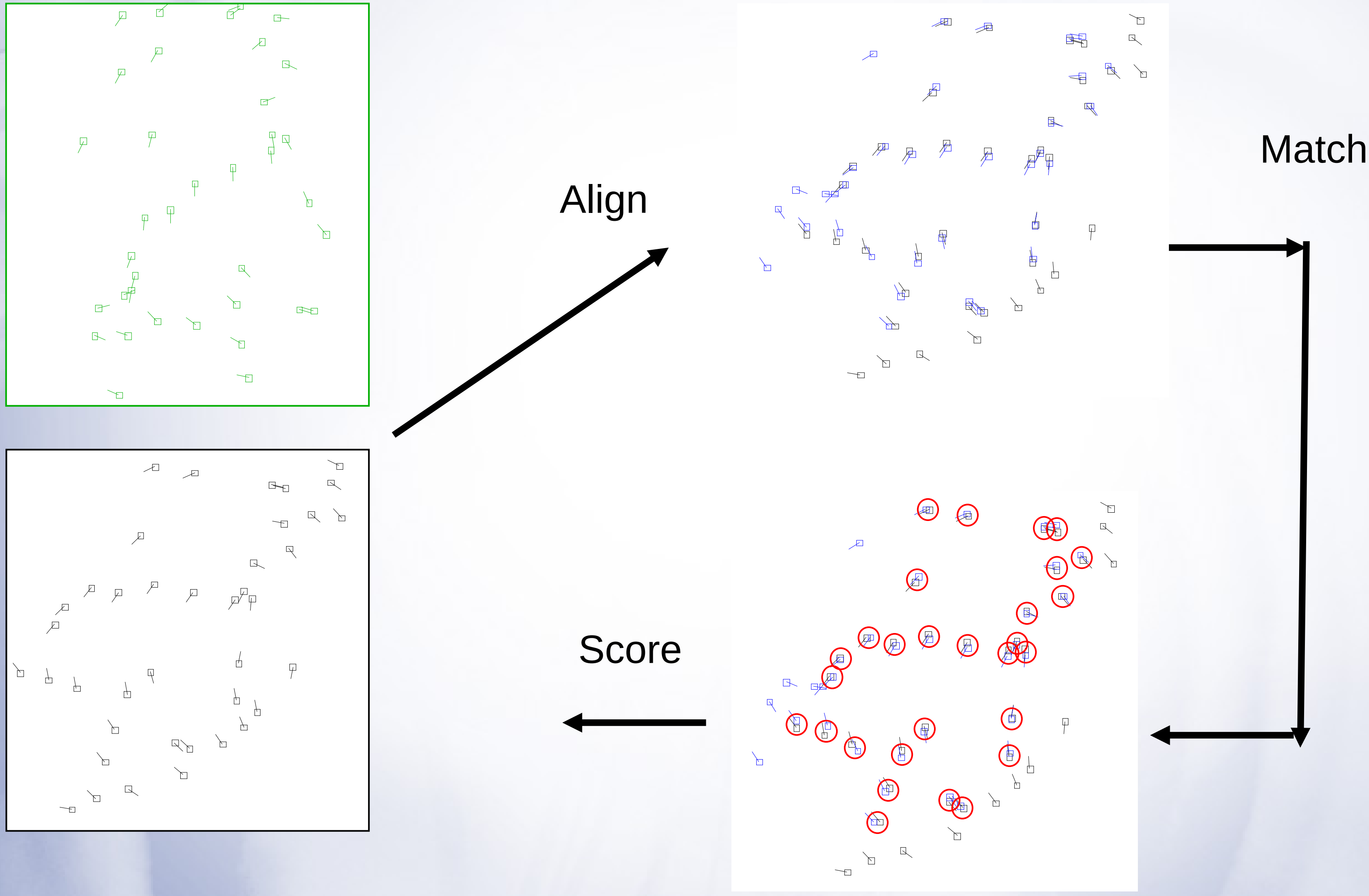
Fingerprint Matching

Find the similarity between two fingerprints

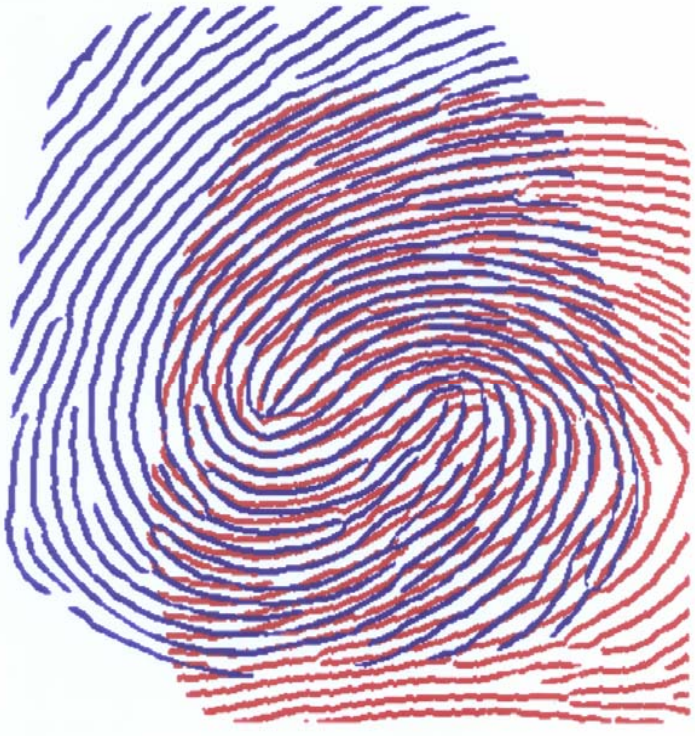
Fingerprints from the same finger

Fingerprints from two different fingers

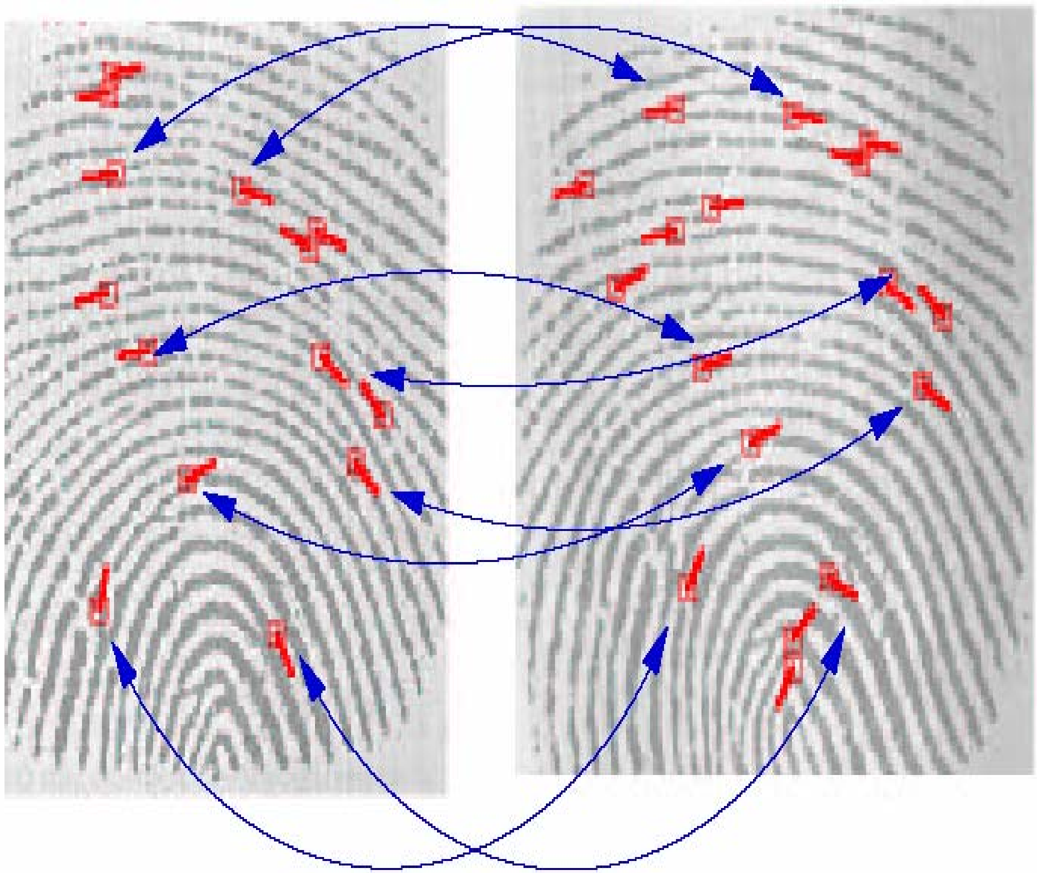
Minutiae Matching



Matching Methods



Two different impressions of the same finger using a Digital Biometrics scanner.



Direct matching **Minutiae matching**

For minutiae matching: Relative configuration of ridge endings and branching between two impressions of the same finger.

Fingerprint Matching

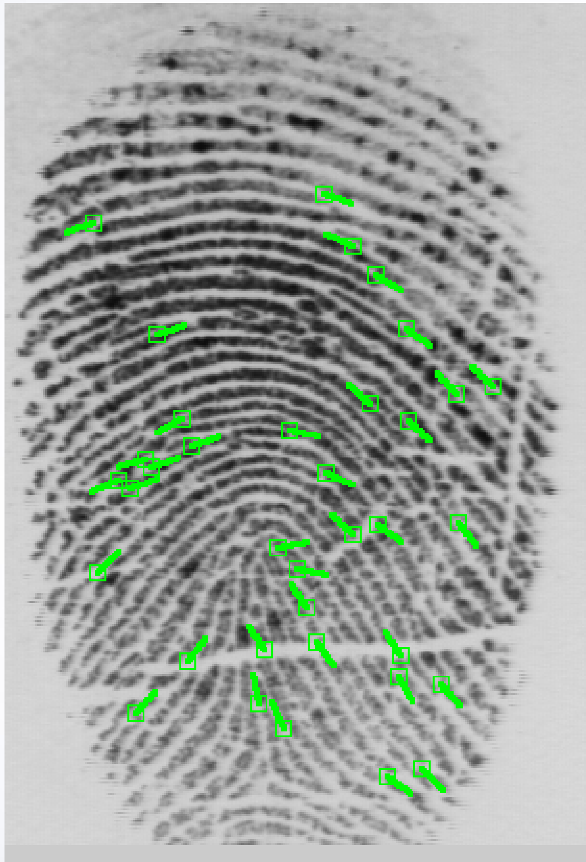
- There are two additional challenges involved in determining the correspondence between two aligned fingerprint representations:

  (i) Dirt/leftover smudges on the sensing device and the presence of scratches/cuts on the finger either introduce spurious minutiae or obliterate the genuine minutiae;

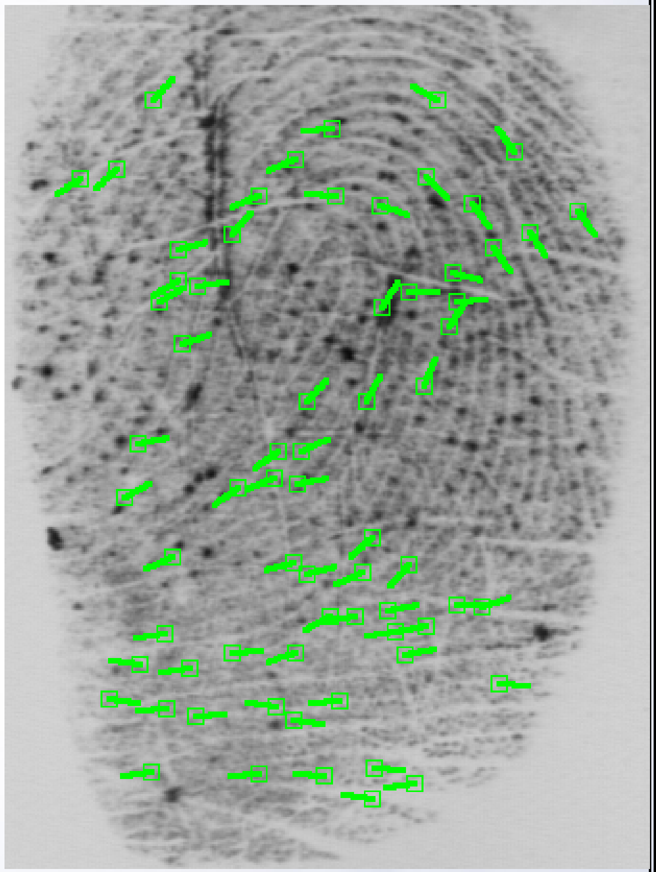
  (ii) Variations in the area of finger being imaged and its pressure on the sensing device affect the number of genuine minutiae captured and introduce displacement of the minutiae from their “true” locations due to elastic distortion of the fingerprint skin.

False Minutiae

Quality Index = 0.96
False Minutiae=0



Quality Index = 0.53
False Minutiae=7



Quality Index = 0.04
False Minutiae=27

Matching Strategies

- A number of strategies have been employed in the literature to solve the alignment problem.
- Typically, it is assumed that the alignment of the test and template fingerprints involve an overall displacement (translation) and rotation.
- The scale variations, shear transformations, local elastic deformations are often overlooked in the alignment stage.
- In image based representations, the alignment of the prints may be obtained by optimizing their image correlation.
- In ridge representations of the fingerprints, portions of ridges may be used to align the prints
- In minutiae based representations, typically, the alignment process uses predominantly minutia positions; minutia angles are not significantly involved because they are vulnerable to image noise/distortion.

Matching Strategies

- In image based representation, the correlation coefficient generated during the alignment can serve as a matching score.
- The elastic deformation, shear transformation, and scale variations may impose severe limitations on the utility of image correlation and image based representations.
- In an *elastic* minutia based matching, the test minutia are searched in a square region centered (bounding box) around each template minutia in the aligned representation.
- The elastic matchers account for small local elastic deformations.

Matching Strategies

- There are several approaches to converting minutia correspondence information to a matching *score*. One straightforward approach for computing the score *S* is:

$$S = \frac{100 M_{PQ} M_{PQ}}{M_P M_Q} \qquad (1)$$

where M_{PQ} is the number of corresponding minutiae and M_P, M_Q, are the total number of minutia in template and test fingerprints.

Matching Strategies

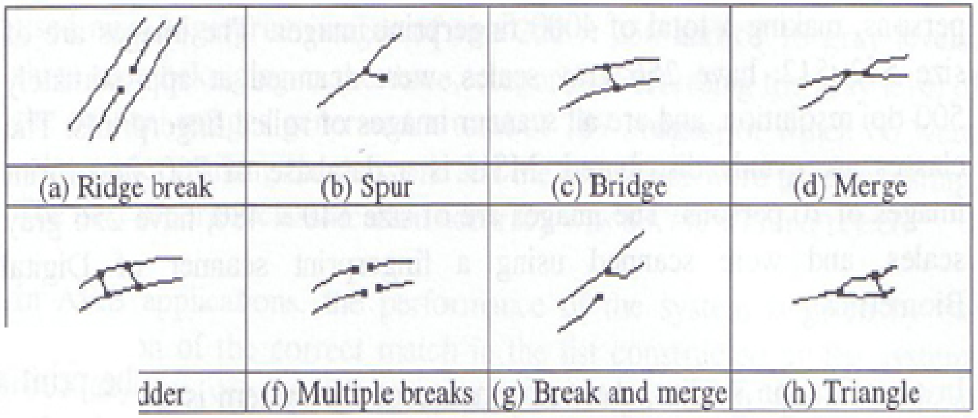
- In some matchers, the total number of minutiae (M_P and M_Q in Eq. (1)) is not used. After the correspondence is determined, an *overall* bounding box only for corresponding test and template minutia is computed. The matching score S_B is then computed as:

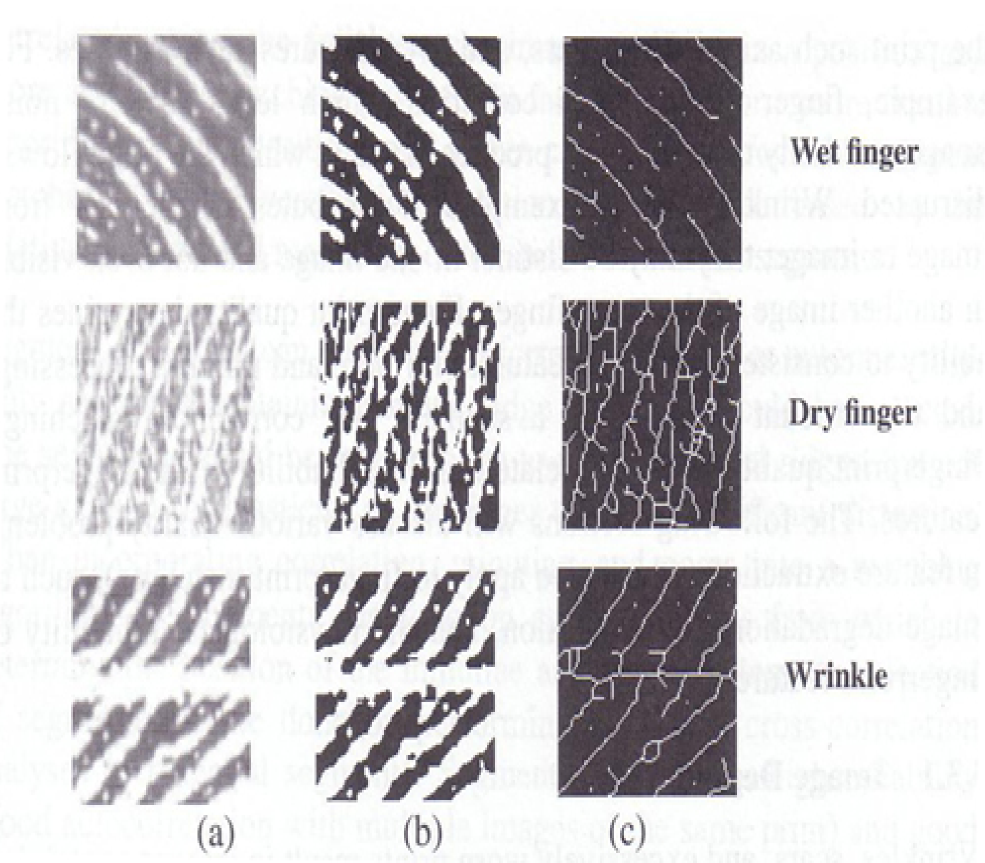
$$S_B = \frac{100\, M_{PQ} M_{PQ}}{M_{Pb} M_{Qb}} \qquad (2)$$

where M_{PQ} is the number of corresponding minutiae and M_{Pb}, M_{Qb} are the number of minutia in the overall bounding boxes computed for template and test fingerprints, respectively.

Potential Problems

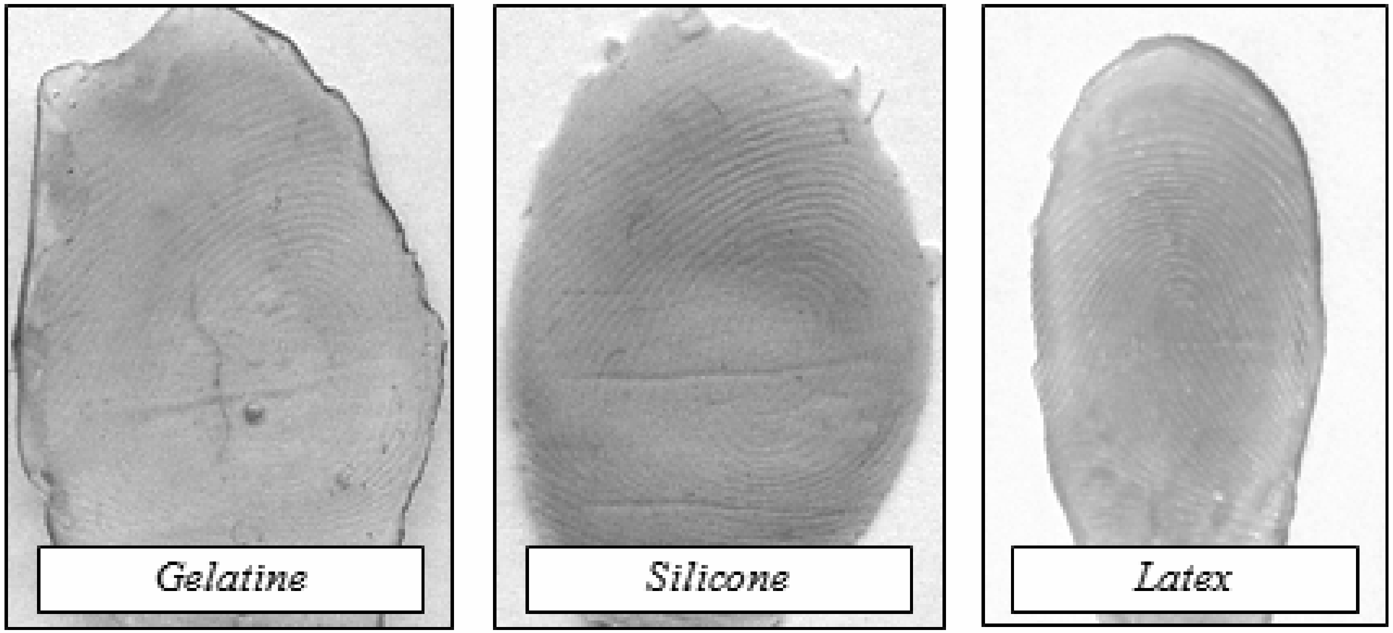
- Physical condition of the fingers might cause lower quality of image.

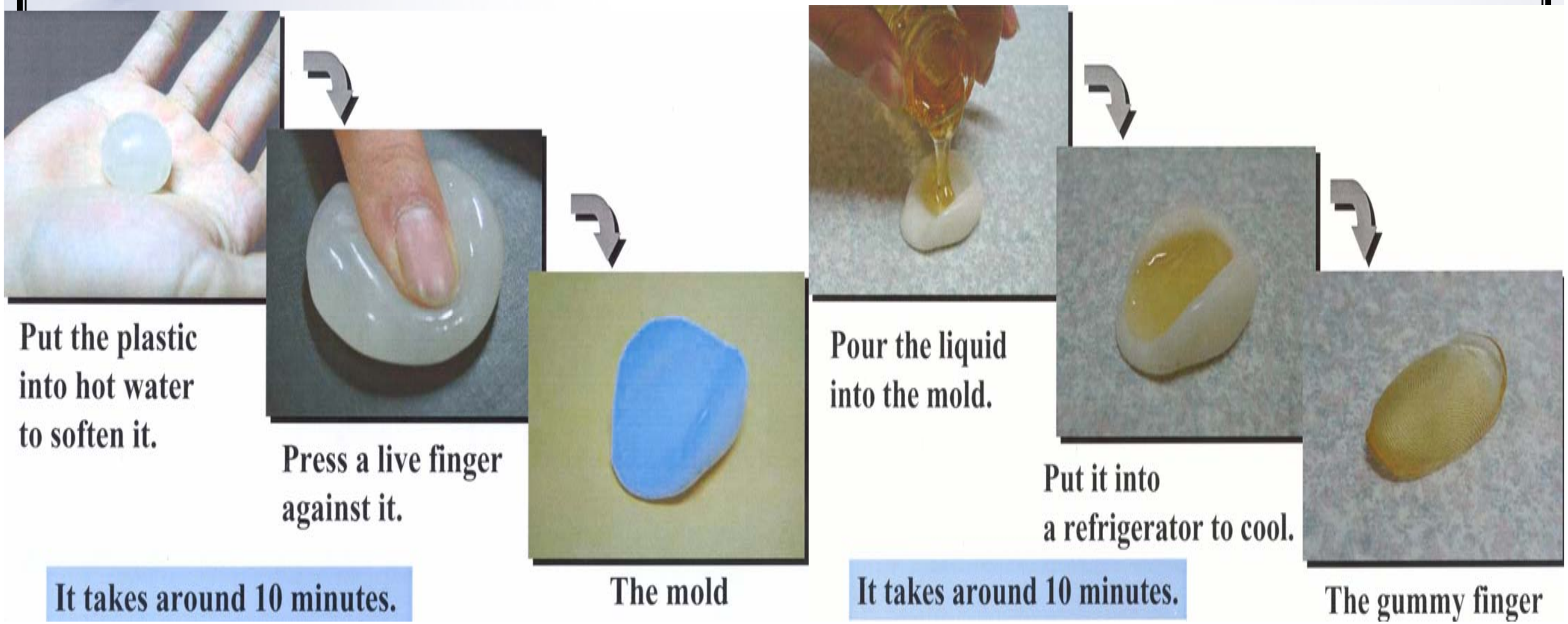




- Lack of reliable algorithm to extract scanned image into minutiae.
- The person who is missing fingers.
- Fake fingerprint
- Inconvenience

Finger Scan Threats





Fingerprint

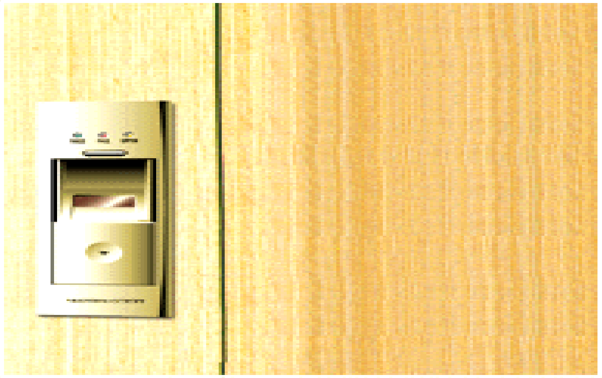
Fingerprint Applications

Smart Card

Computer Login

Access Control

Access Control

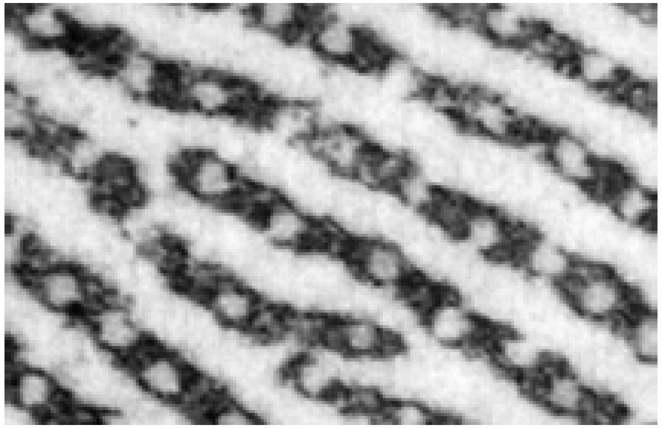


Keyless Locker

Immigration Fingerprint Record

Fingerprint - Strengths

- **Mature and proven core technology, capable of high levels of accuracy (EER at 0.1%, Station of Bioscrypt Inc.)**
- **Can be deployed in a range of environments**
- **Employs ergonomic, easy-to-use devices**
- **Ability to enroll multiple fingers to increase system accuracy and flexibility**
- **Fingerprint Verification Competitions**
- **High accuracy if using pore features**



Fingerprint - Weaknesses

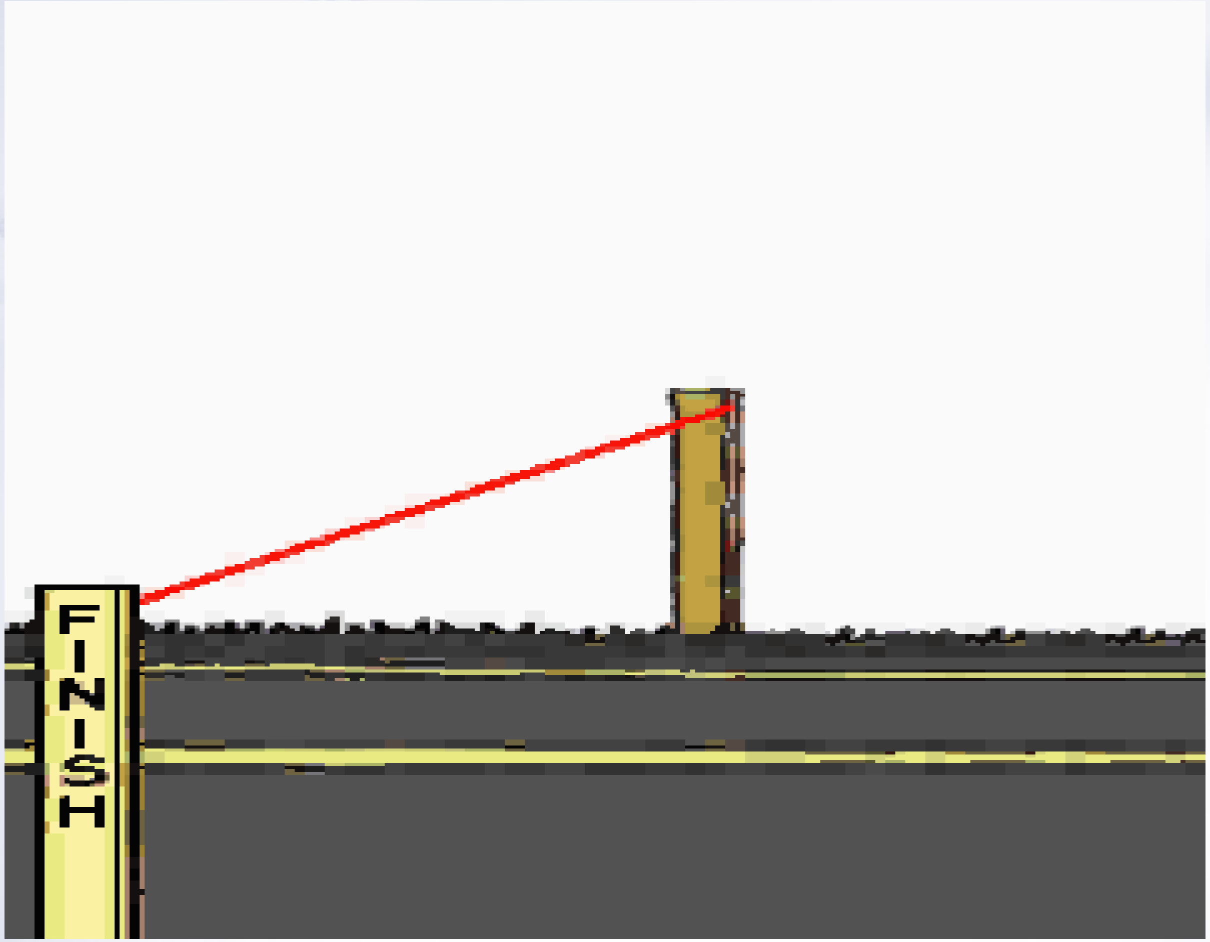
Fingerprint

- **Cuts and bruises on finger; dry or oily finger; Most devices are not able to enroll a small percentage of users (about 5 – 10%)**
- **Liveness detection is a great problem ("Detectors licked by gummy fingerprint" Nature 417, 676. News), wear and tear of sensor. Also since touchable, fingerprint impression is often left on the sensor**
- **New compact solid-state sensors capture only a small portion of the fingerprint; requires user habituation**

- **Performance can deteriorate over time**

Questions?

- In general, there are different features extracted from three levels. Please point out what kinds of features can you extract?
- Even over 100 years' history, fingerprint is still not used perfectly. What is the main problems in the current fingerprint recognition? Do you have any idea to solve them?
- How to obtain an alive fingerprint image? Do you have any detecting methods?



END