Fingerprint Recognition II

COMP 388-002/488-002 Biometrics

Daniel Moreira

Fall 2025

LOYOLA
UNIVERSITY CHICAGO

Today we will…

Get to know
Fingerprint acquisition and enhancement.

Today's Attendance

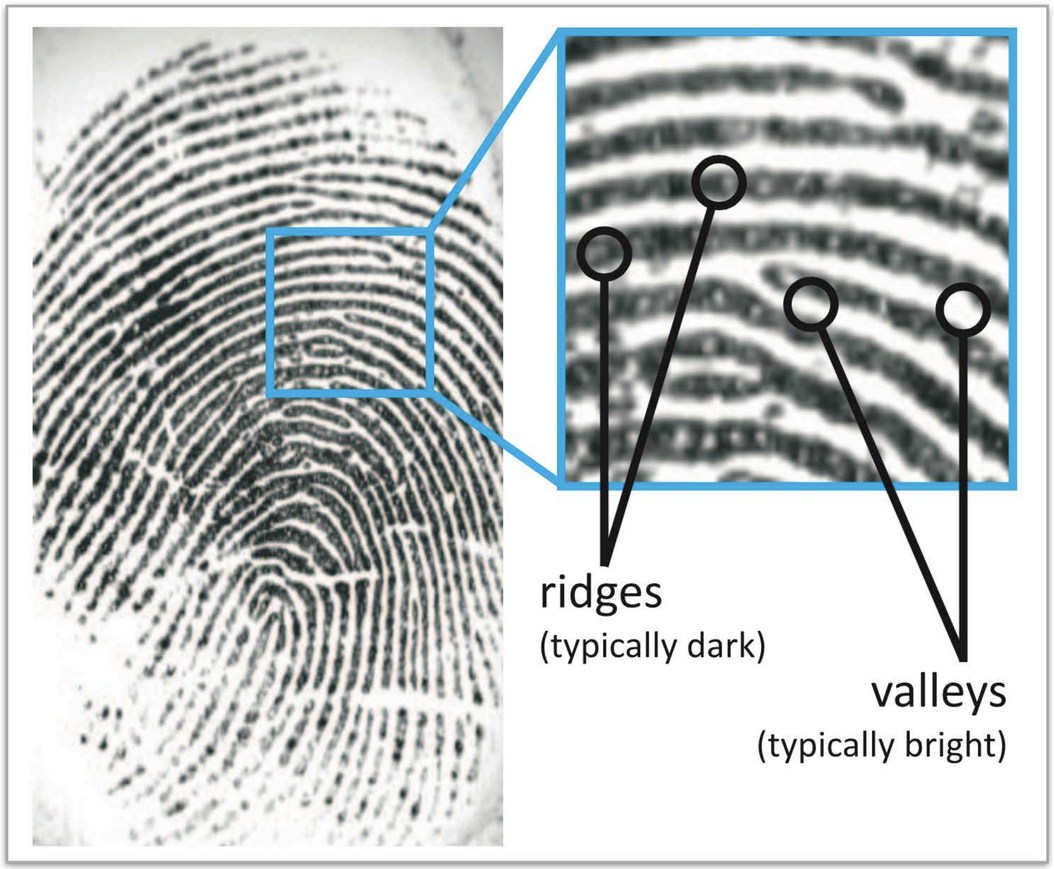
Please fill out the form

forms.gle/XHPxsvDNKa7xGzih8

Features

What do we observe in fingerprints?

Ridges and Valleys
Embryology hypothesis:
Ridges appear as a result of the stresses in the womb during the growth of the fetus.



Source: Dr. Adam Czajka

Features

What do we observe in fingerprints?

Beyond Ridges and Valleys
Three types of features,
from coarse to fine levels:

- Level-1 Features
- Level-2 Features
- Level-3 Features

Features

What do we observe in fingerprints?

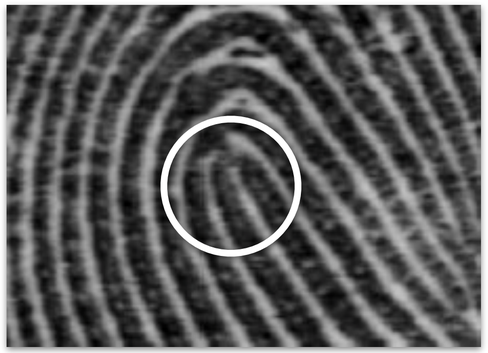
Beyond Ridges and Valleys
Three types of features,
from coarse to fine levels:

- **Level-1 Features**
- Level-2 Features
- Level-3 Features

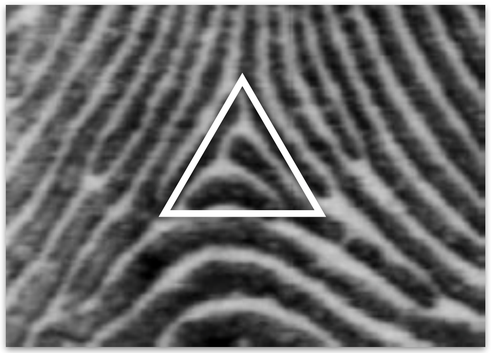
Features

Level-1 Features
Observe singular points and core.
Useful capture resolution: 250 ppi (pixels per inch)

Singular Points



loop



delta

Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

Core

Up-most singular point

or (in case of no singular point)

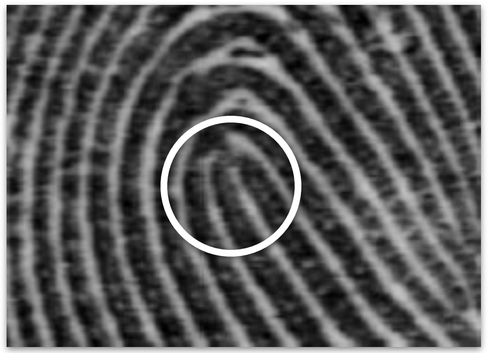
Point of maximum ridge curvature.

Features

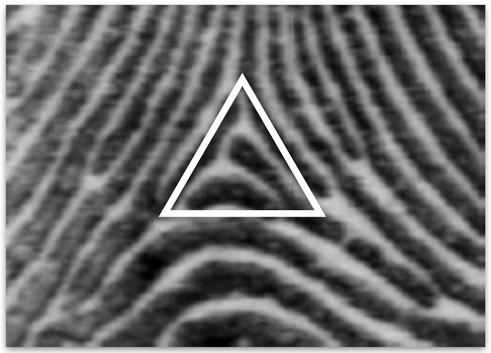
Level-1 Features

Observe singular points and core.

Usage of Singular Points and Core



loop



delta

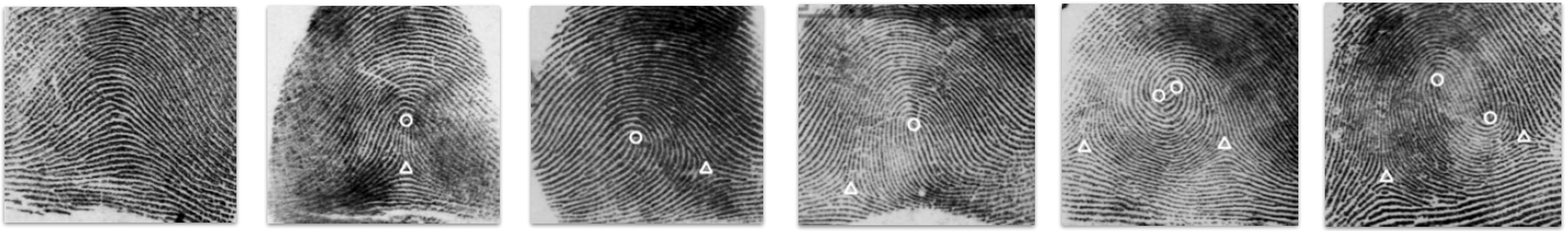
Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

Alignment of two samples.
Fingerprint classification.

Features

Fingerprint Classification

Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011



plain arch
4%

tented arch
3%

left loop

right loop

65%

whorl
24%

twin loop
4%

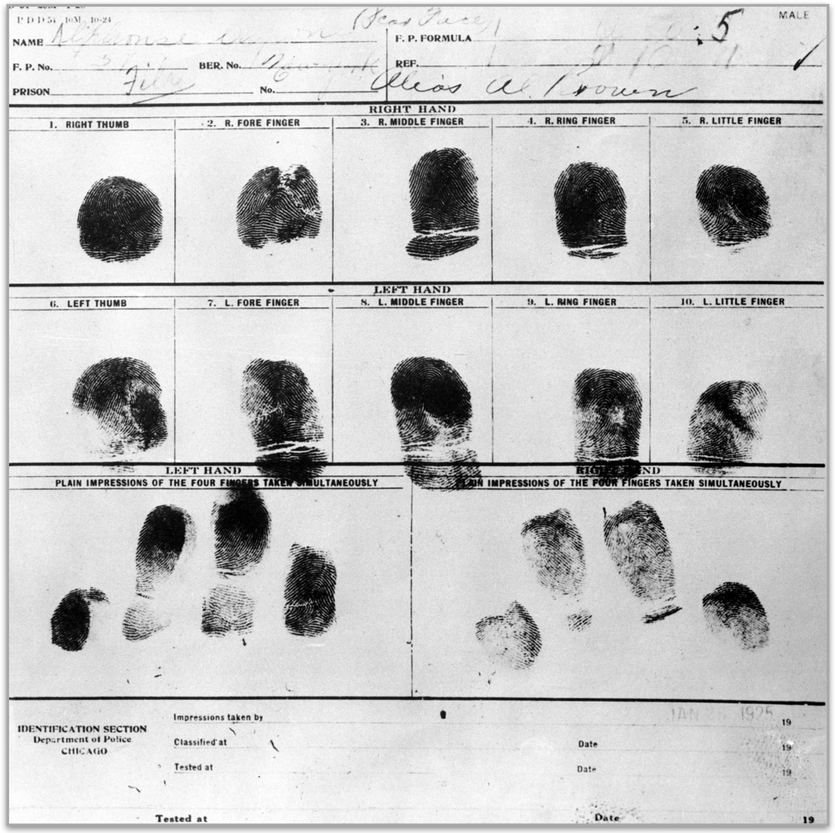
Percentages: frequencies of observation.

Features

How useful are level-1 features?

FBI Automated Fingerprint Identification system (AFIS)
More than 200 million dactyloscopy cards.
Varied quality of samples.

Estimated: one untrained person would spend **67 years** to search 1.7 million cards.



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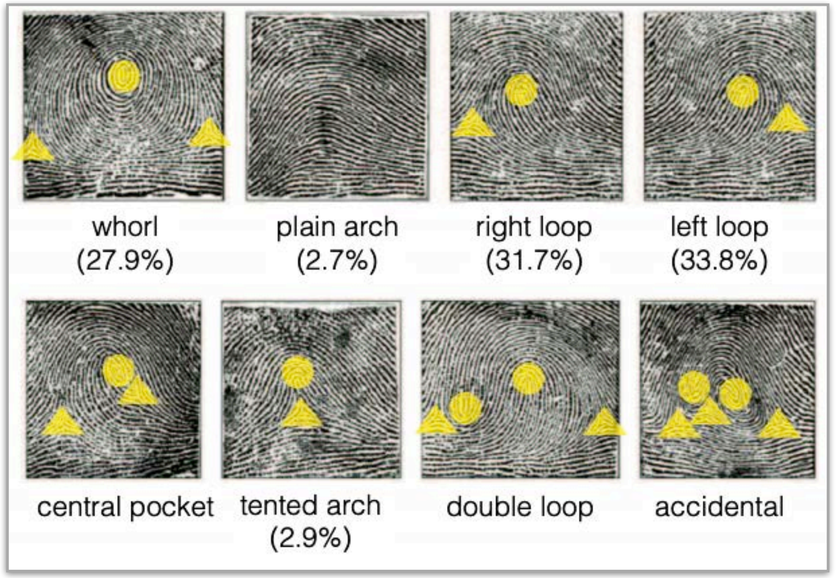
Features

How useful are level-1 features?

FBI Automated Fingerprint Identification system (AFIS)
More than 200 million dactyloscopy cards.
Varied quality of samples.

Thanks to fingerprint classification through level-1 features, this time is reduced to **20 min**.



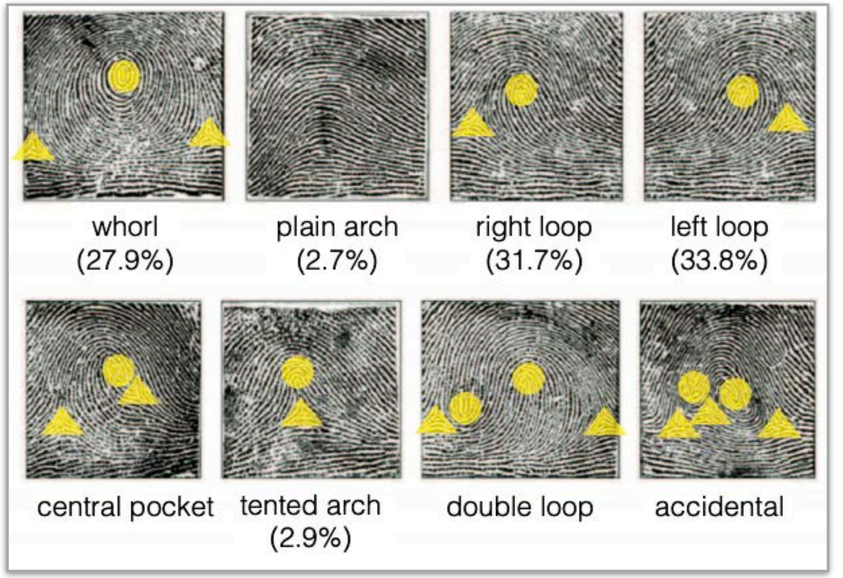
Henry's features, an alternative classification of level-1 features with 8 classes.

Features

How useful are level-1 features?

FBI Automated Fingerprint Identification system (AFIS)
More than 200 million dactyloscopy cards.
Varied quality of samples.

And a computer-based solution can do it in seconds, benefitting from the same features.



Henry's features, an alternative classification of level-1 features with 8 classes.

Features

What do we observe in fingerprints?

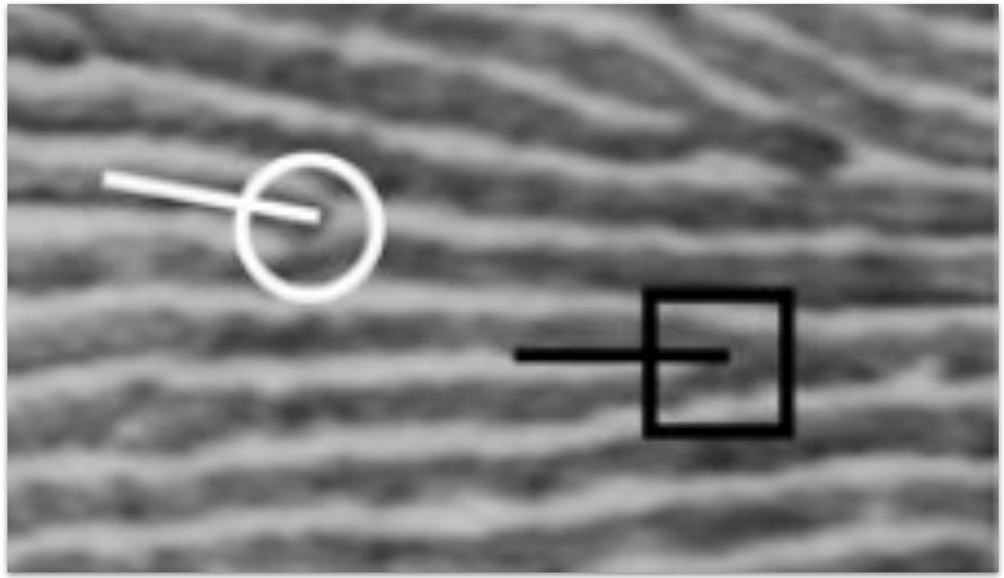
Beyond Ridges and Valleys
Three types of features, from coarse to fine levels:

- Level-1 Features
- **Level-2 Features**
- Level-3 Features

Features

Level-2 Features
Observe minutiae (Galton's details).
Useful capture resolution: 500 ppi

Ridge Ending

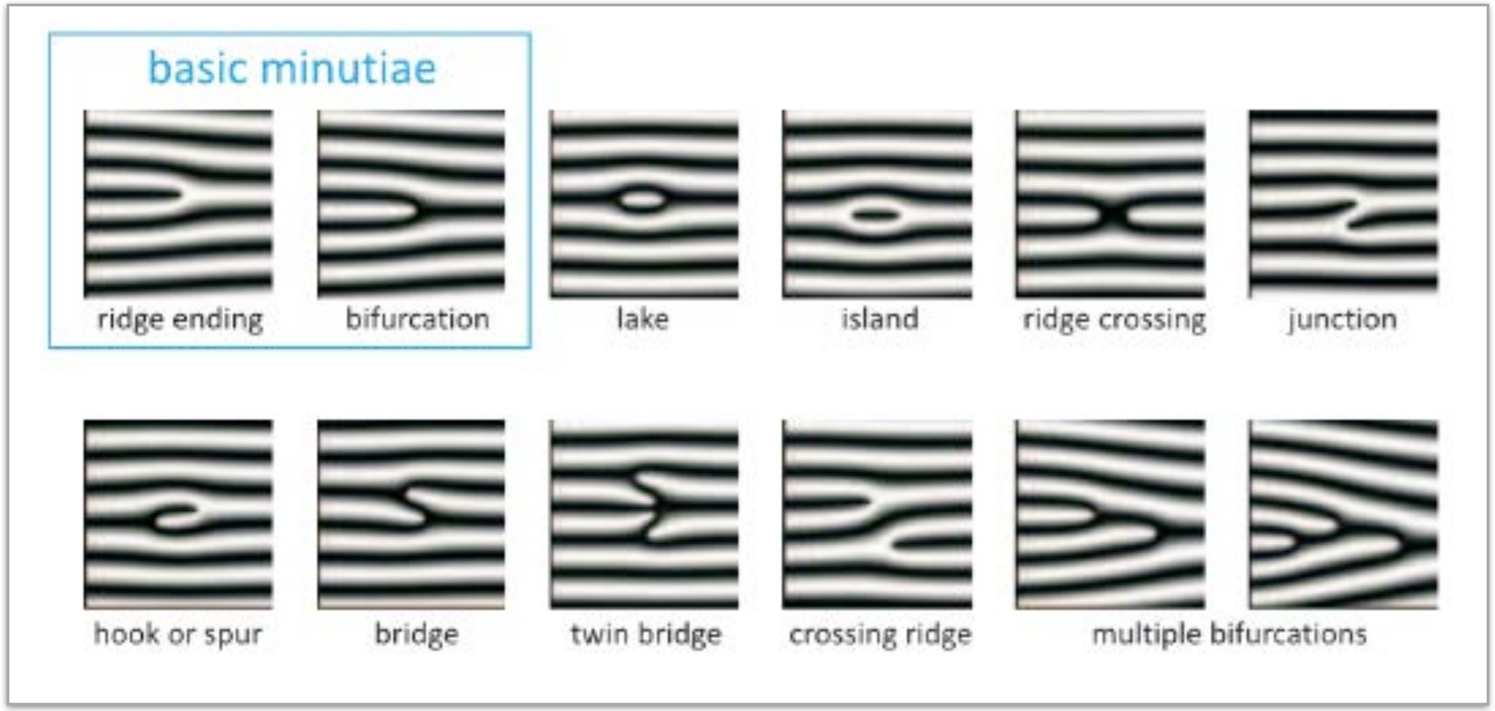


Ridge Bifurcation

Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

Features

Level-2 Features
Alternative minutiae.



Source:
www.optel.com.pl

Features

Level-2 Features

Usage of minutiae
Fingerprint matching.

More details on **how** to do it
in the upcoming classes.

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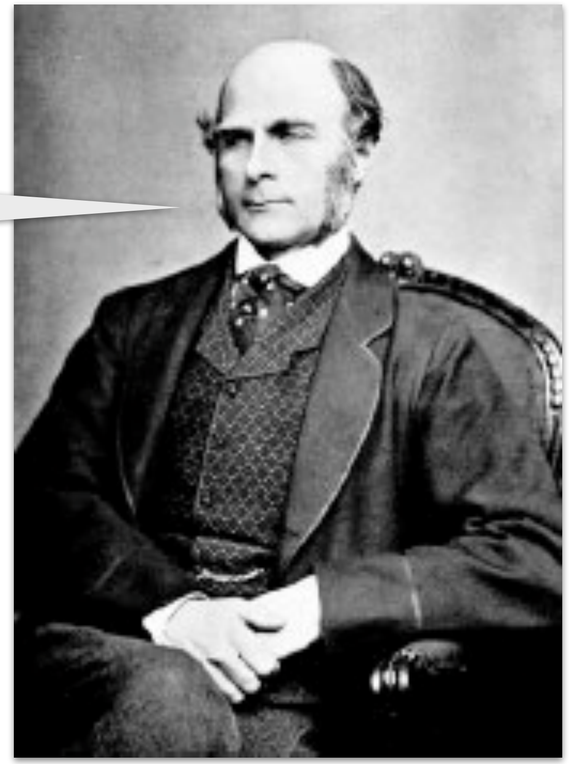
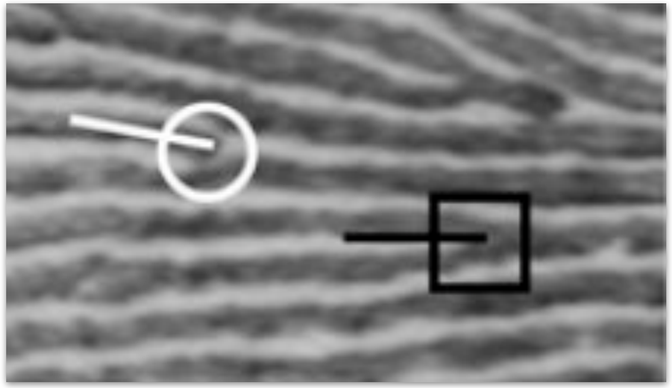
Features

Level-2 Features

Galton's Estimate

Given 2 similar fingerprints, what is the chance they come from different people?
I'll tell you: 1 in 64 billion.





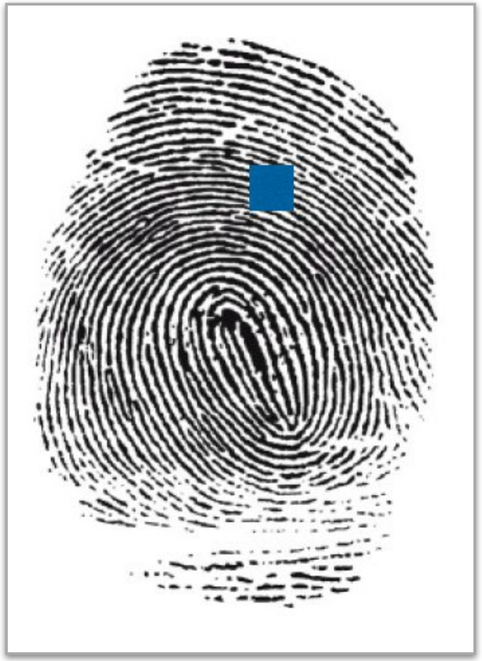
Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

Features

Level-2 Features

Galton's Estimate

Rationale
What would be the smallest portion of
a fingerprint leading to a 1/2 chance
of being correctly guessed as belonging
to a particular individual?



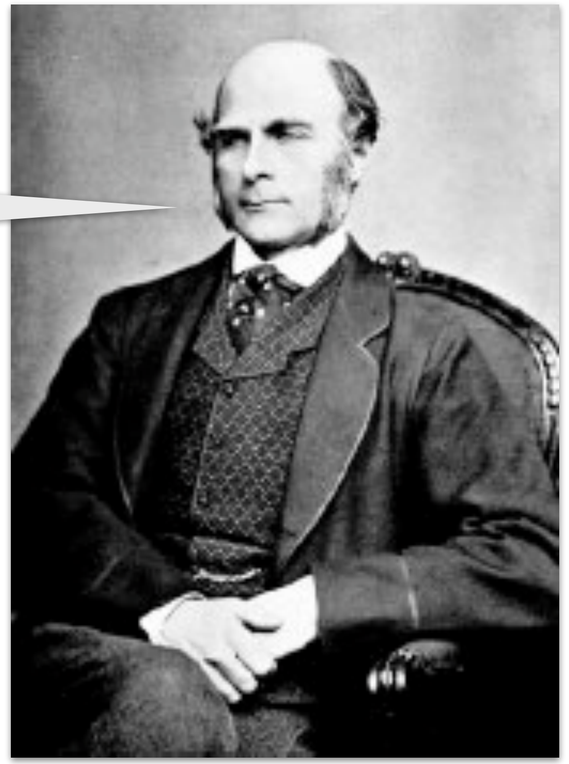
Source:
Dr. Walter Scheirer

Features

Level-2 Features

Galton's Estimate

After a few trials, let me say:
A square containing 5-6 ridges.



Rationale
What would be the smallest portion of
a fingerprint leading to a 1/2 chance
of being correctly guessed as belonging
to a particular individual?

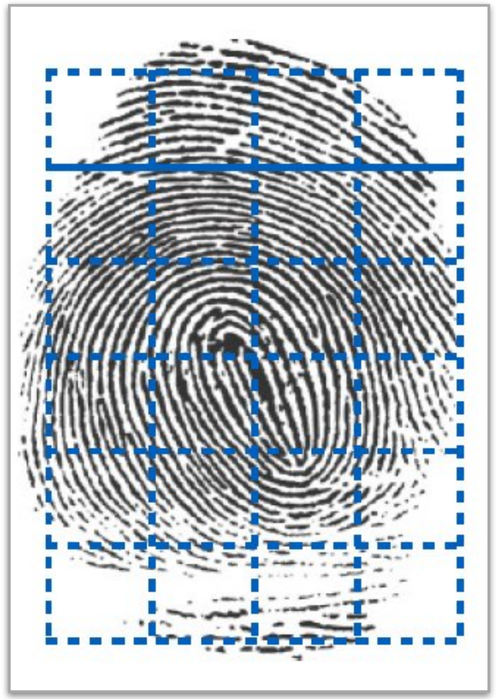
Features

Level-2 Features

Galton's Estimate

A typical fingerprint consists of 24 six-ridge squares.

Hence, the chance of correct full fingerprint guess: $1/2^{24}$



Source:
Dr. Walter Scheirer

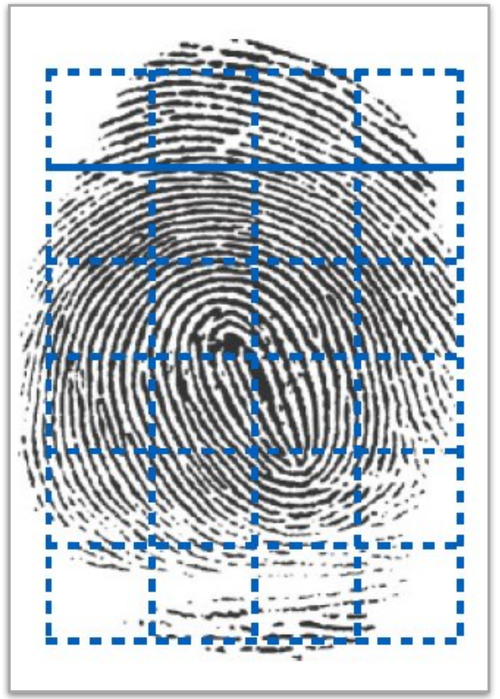
Features

Level-2 Features

Galton's Estimate

Chance of correct guess of squares' disposition: $1/2^{12}$

considering the spatial restrictions



Source:
Dr. Walter Scheirer

Features

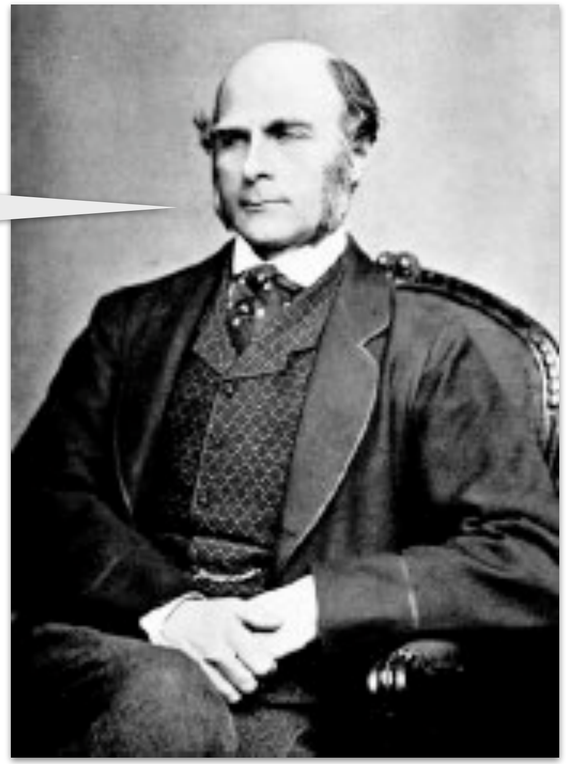
Level-2 Features

Galton's Estimate

Total chance of a random fingerprint match a particular one:

$1/2^{24} \times 1/2^{12} = 1/2^{36}$

1 in 64 billion



Features

Level-2 Features

Galton's Estimate

Total chance of a random fingerprint match a particular one:

$$1/2^{24} \times 1/2^{12} = 1/2^{36}$$

How many humans have ever lived?

107 billion

https://www.bbc.com/news/magazine-16870579

Features

What do we observe in fingerprints?

Beyond Ridges and Valleys
Three types of features, from coarse to fine levels:

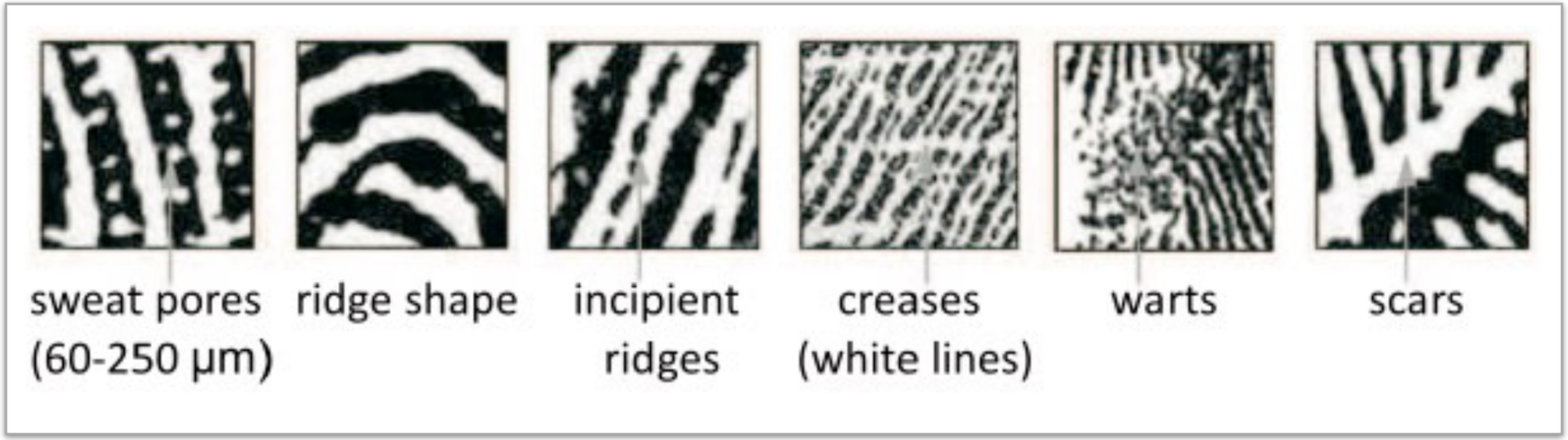
- Level-1 Features
- Level-2 Features
- **Level-3 Features**

Features

Level-3 Features

Observe sweat pores, ridge shape, and lifetime acquired marks.

Useful capture resolution: 1000 ppi



Jain, Chen, and Demirkus
Pores and Ridges: High-Resolution Fingerprint Matching Using Level 3 Features
IEEE T-PAMI, 2007

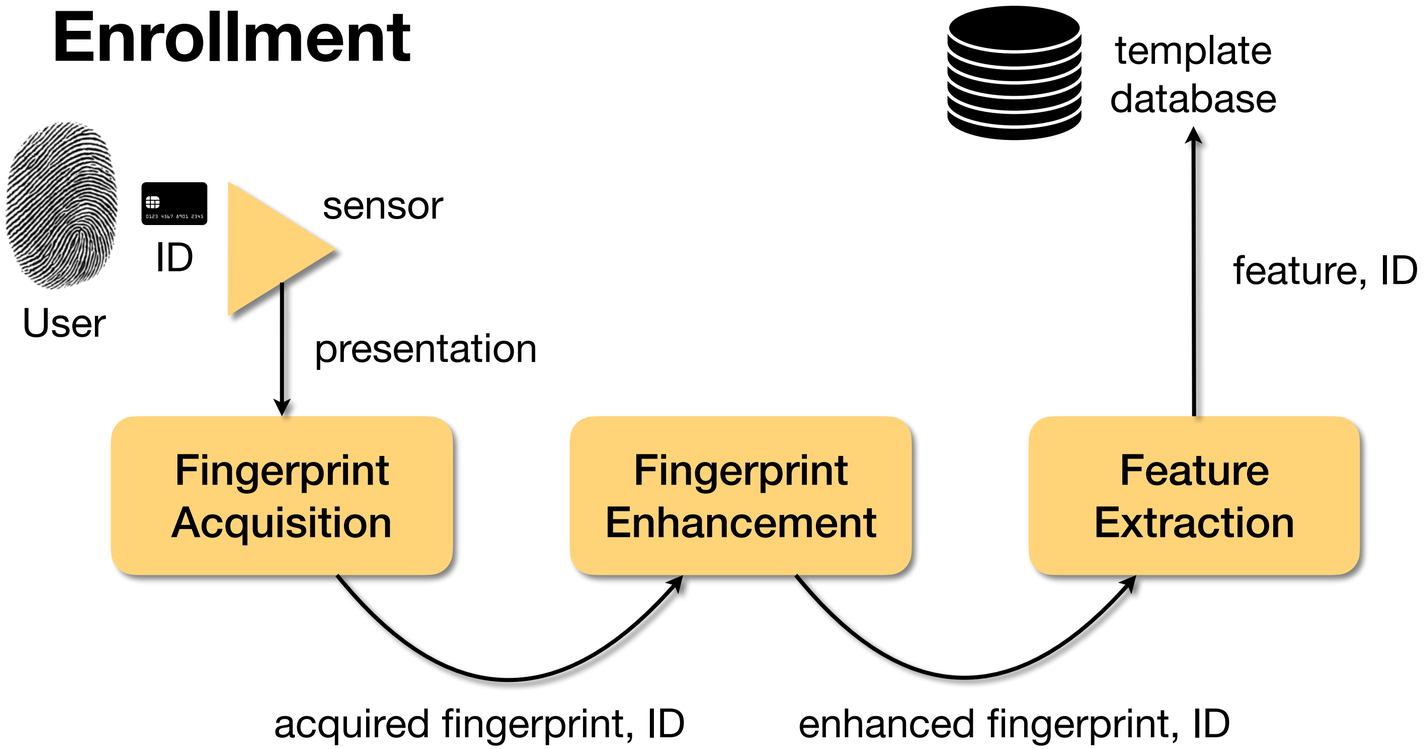
Features

Level-3 Features
Observe sweat pores, ridge shape, and lifetime acquired marks.

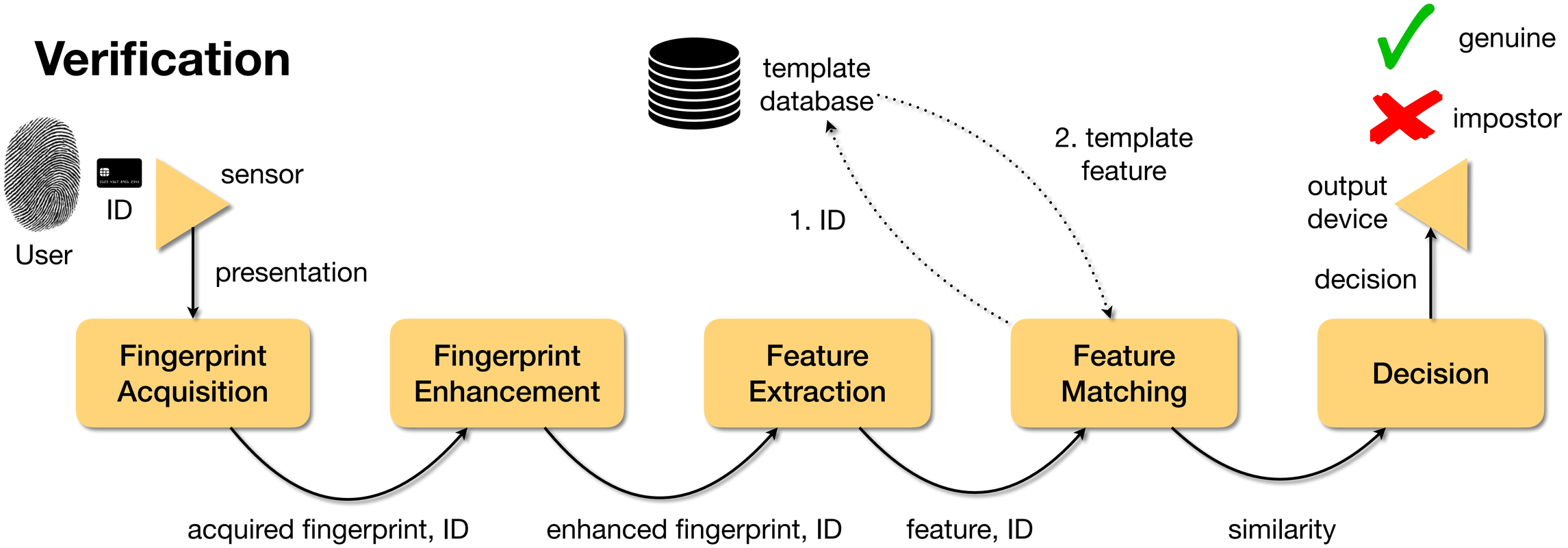
Usage of Level-3 Features
Fingerprint liveness detection.
Rule-out questioned fingerprint matches.

https://www.bbc.com/news/world-latin-america-21756709

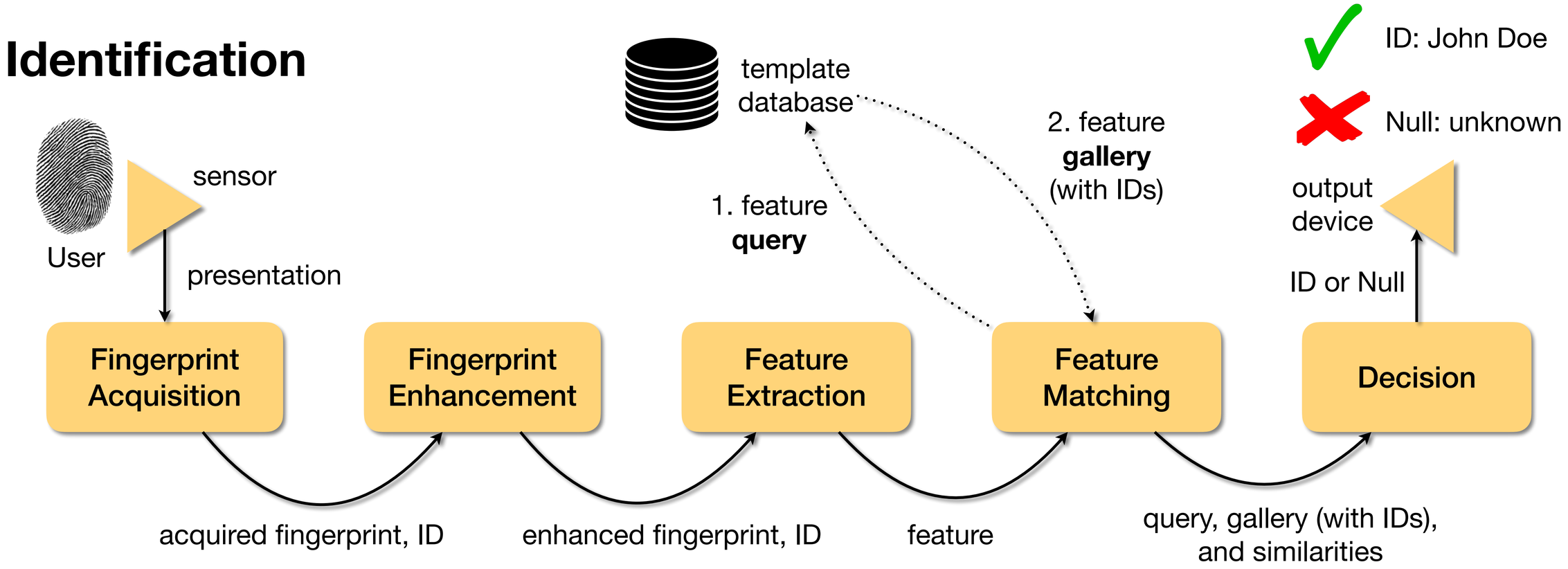
Fingerprint Recognition



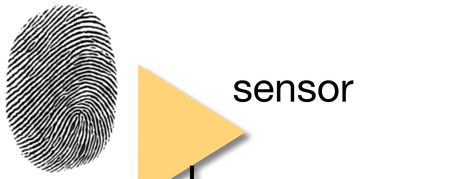
Fingerprint Recognition



Fingerprint Recognition



Fingerprint Recognition



sensor

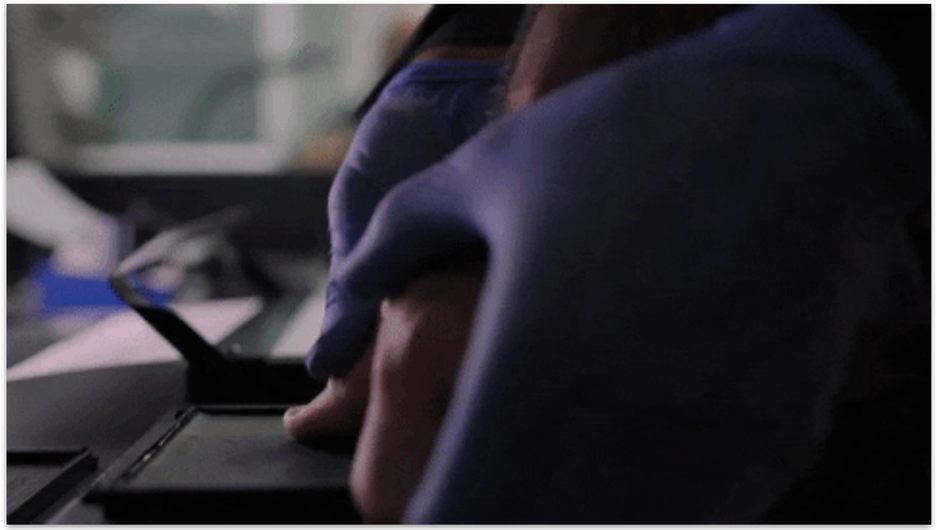
User

presentation

Fingerprint Acquisition

Acquisition

Off-line versus On-line



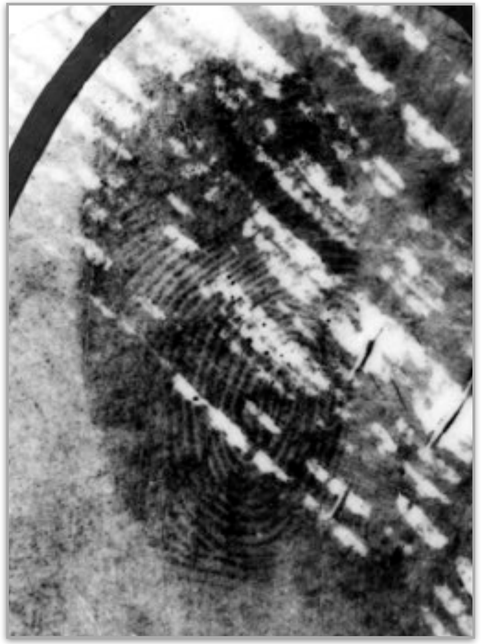
Acquisition

Off-line Acquisition
Same fingerprint.

Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

rolled inked fingerprint

slap inked fingerprint

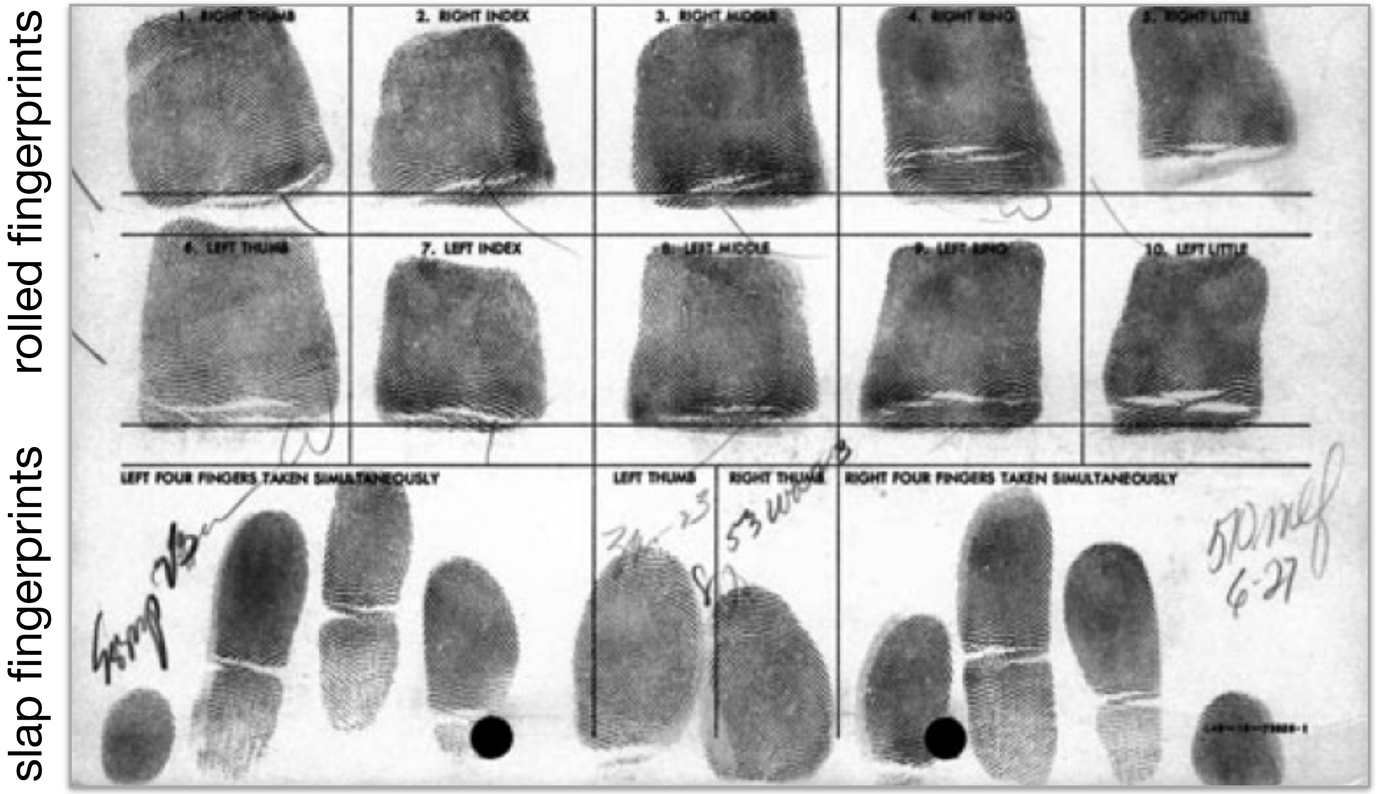


latent fingerprint

Acquisition

Off-line Acquisition

Scanning of dactyloscopy cards.



Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

Acquisition

Off-line Acquisition

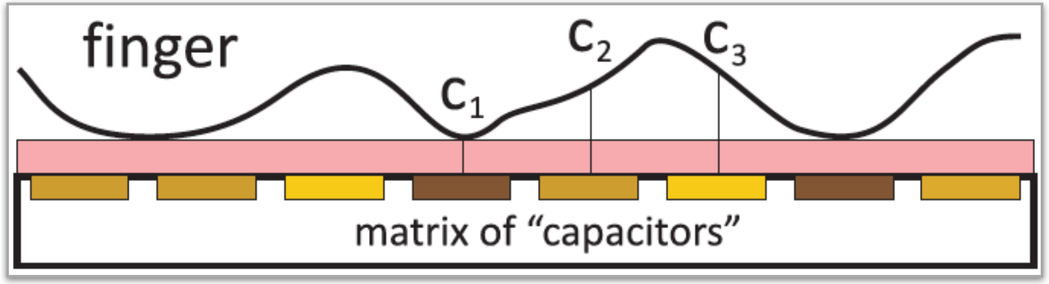
Photographing of
latent fingerprints.

Source: Dr. Adam Czajka

Acquisition

On-line Acquisition

Capacitive sensors (1/6)
Ridges and valleys will generate different charges C_n, which will form different image segments.



Source: Dr. Adam Czajka

Low cost, but sensitive to dirt and moistness.

Typical resolution: 300 dpi (dots per inch).

Acquisition

On-line Acquisition

Capacitive sensors (1/6)
Device and sample.

Precise Biometrics
Source: Dr. Adam Czajka

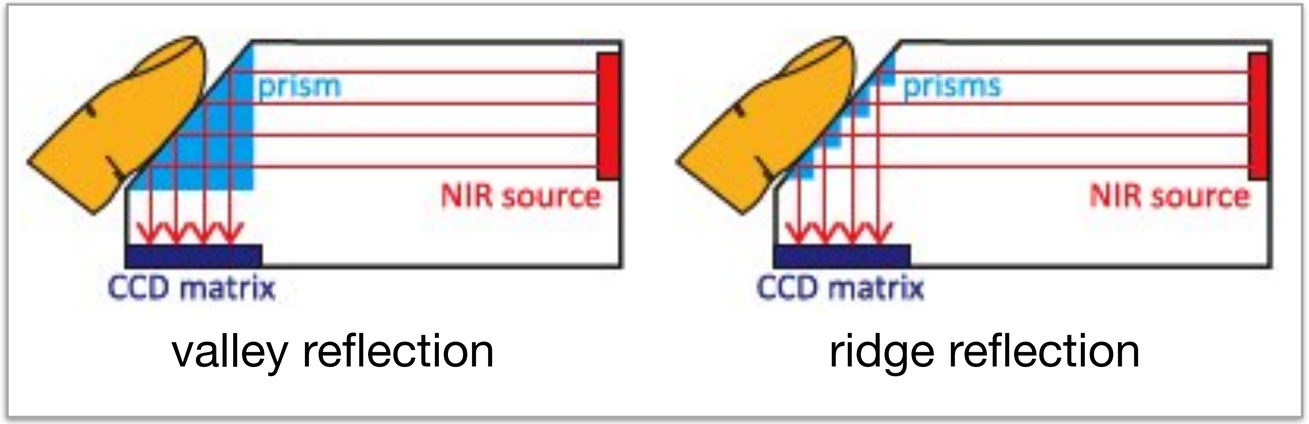
Source: http://
bias.csr.unibo.it/fvc2002/

Acquisition

On-line Acquisition

Optical sensors (2/6)
Ridges won't be reflected on charge-coupled device (CCD) matrix, contrary to valleys, leading to darker image segments.

Source: Dr. Adam Czajka



Typical resolution: 400-1000 dpi.

Acquisition

On-line Acquisition

Optical sensors (2/6)
Devices.

Identix
Source: Dr. Adam Czajka

Guardian

Acquisition

On-line Acquisition

Optical sensors (2/6) - Samples.

Source: Dr. Adam Czajka

slap
Biometrika FX2000

rolled
CrossMatch LS320

thumbs
L1 TP4100

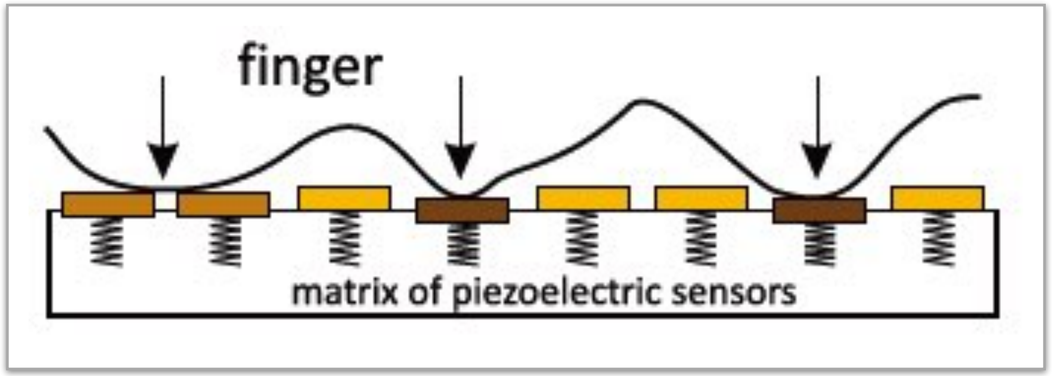
little, ring, middle, and index
L1 TP4100

Acquisition

On-line Acquisition

Pressure sensors (3/6)
Also known as piezoelectric.
Ridges will cause stronger pressure than valleys, forming different image segments.

Source: Dr. Adam Czajka



Robust to moistness.
Typical resolution: 400 dpi.

Acquisition

On-line Acquisition

Pressure sensors (3/6)
Device and sample.

BMF/Hitachi
Source: Dr. Adam Czajka

Source: Dr. Adam Czajka

Acquisition

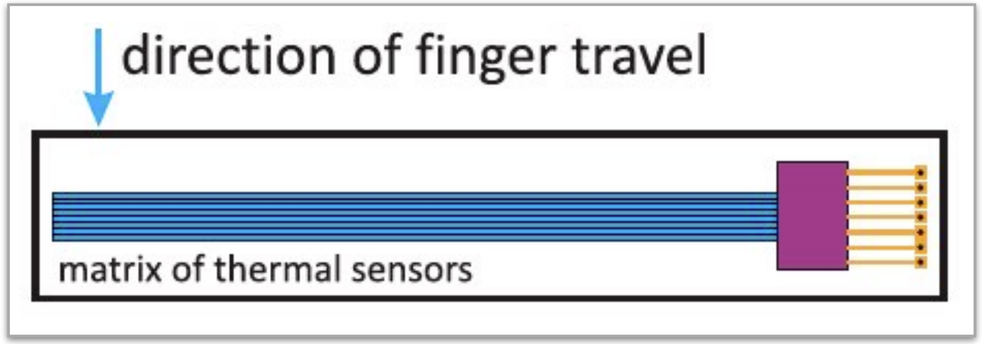
On-line Acquisition

Thermal sensors (4/6)
Based on surface temperature.
Ridges will transfer a different amount of heat when compared to valleys, leading to different image segments.

Acquisition

On-line Acquisition

Thermal sensors (4/6)
Example: Atmel FingerChip
Finger is swept onto the sensor.



Source: Dr. Adam Czajka

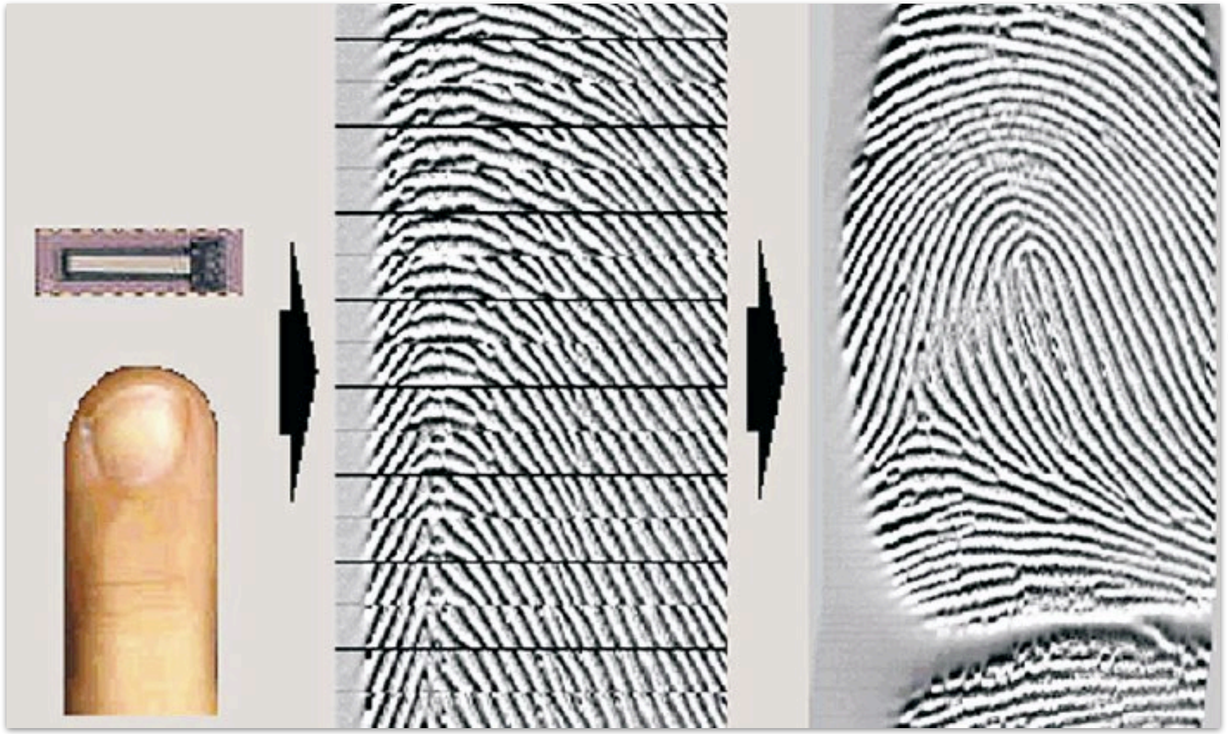
Thin sensor but high resolution
(typically 500 dpi).

While finger is swept, temperature is collected
at discrete time intervals.

Acquisition

On-line Acquisition

Thermal sensors (4/6)
Example: Atmel FingerChip
Sample generation.



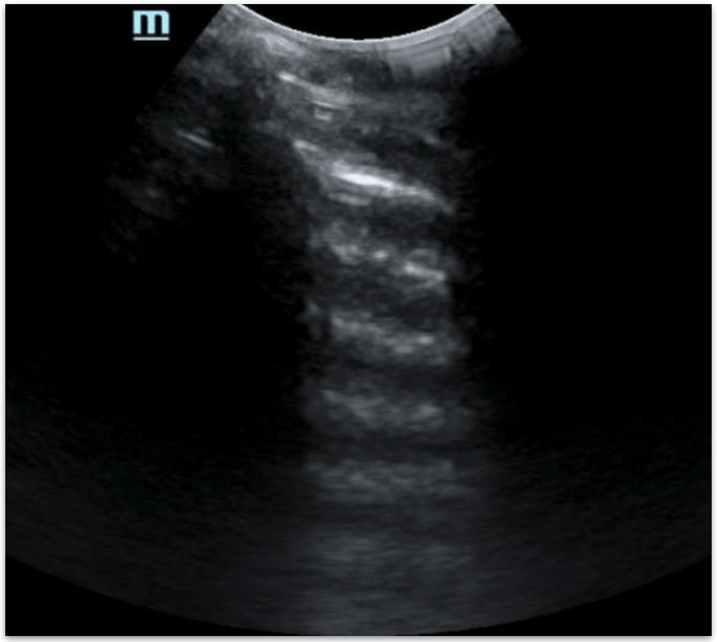
finger sweep discrete collection fingerprint reconstruction

Source: Atmel FingerChip

Acquisition

On-line Acquisition

Ultrasound sensors (5/6)
Measures the scattering of sound waves over the finger surface.
Ridges and valleys will produce different scattering, leading to different image segments.

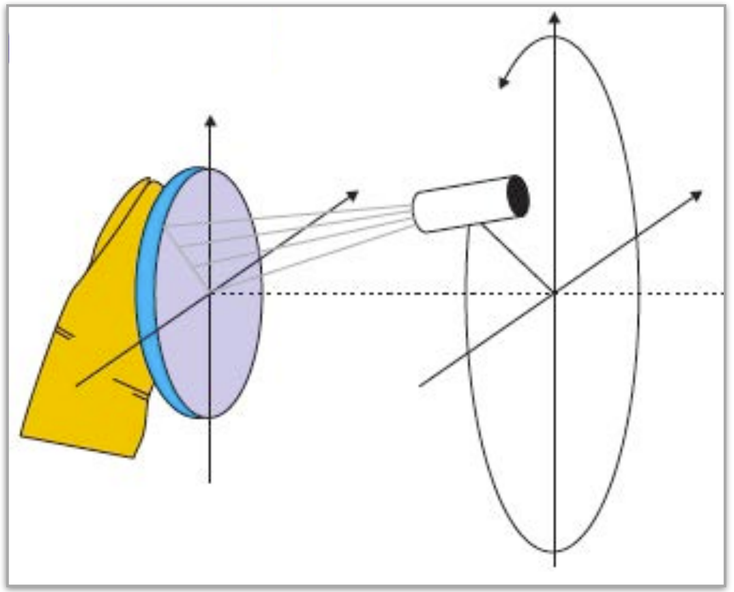


Acquisition

On-line Acquisition

Ultrasound sensors (5/6)
Example: Optel

Transducer moves along a circular trajectory whose central axis is perpendicular to the fingertip.



Source: Dr. Adam Czajka

More expensive. Typical resolution: 250 dpi.
Harder to be spoofed (due to ultrasounds penetration).

Acquisition

On-line Acquisition

Ultrasound sensors (5/6)
Example: Optel
Device and sample.

Source: www.optel.com.pl

Acquisition

On-line Acquisition

Ultrasound sensor (5/6)
Example: Qualcomm Fingerprint

Sensor embedded into the device display.

Source: mashable.com

Acquisition

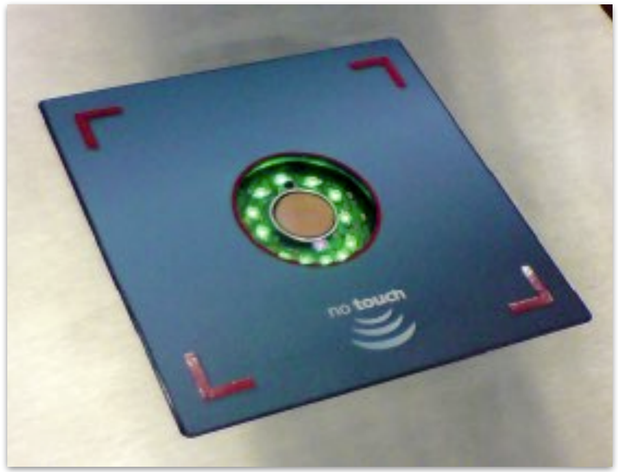
On-line Acquisition

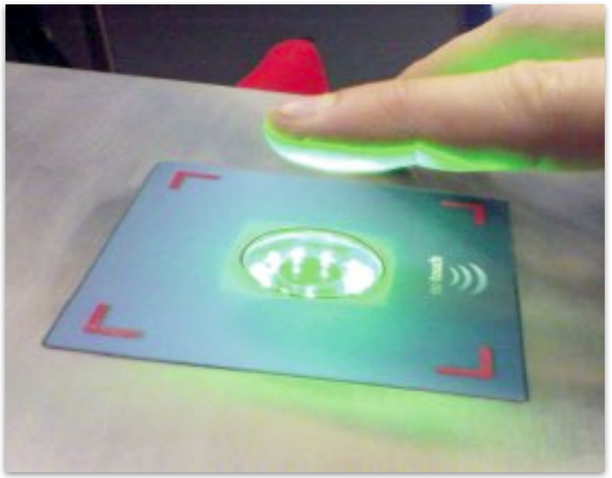
Touchless sensor (6/6)
3D imaging with CCD sensor.

Acquisition

On-line Acquisition

Touchless sensor (6/6)
Example: TST Biometrics Device.



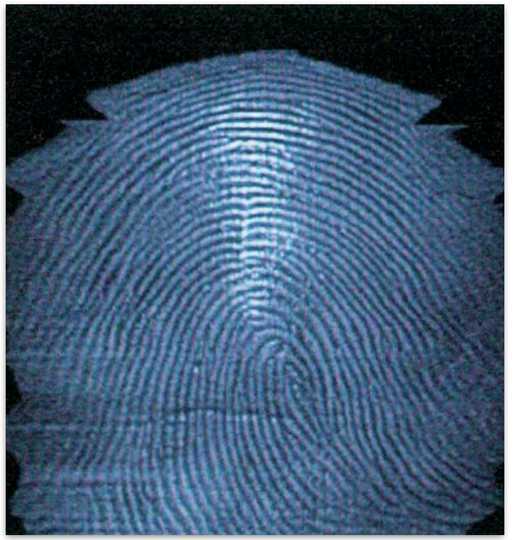


Source: Dr. Adam Czajka

Acquisition

On-line Acquisition

Touchless sensor (6/6)
Example: MorphoWave
Device and sample.



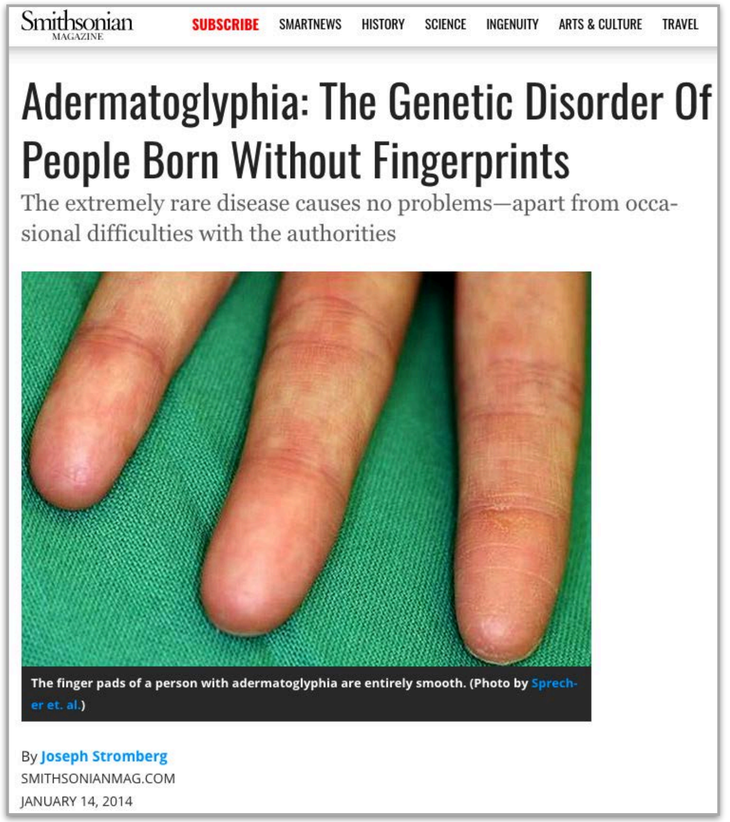
Source: Dr. Adam Czajka

Acquisition

Problems

Adermatoglyphia
Leads to failure to acquire (FTA) and failure to enroll (FTE).

https://www.smithsonianmag.com/science-nature/adermatoglyphia-genetic-disorder-people-born-without-fingerprints-180949338/



Smithsonian MAGAZINE SUBSCRIBE SMARTNEWS HISTORY SCIENCE INGENUITY ARTS & CULTURE TRAVEL

Adermatoglyphia: The Genetic Disorder Of People Born Without Fingerprints

The extremely rare disease causes no problems—apart from occasional difficulties with the authorities

The finger pads of a person with adermatoglyphia are entirely smooth. (Photo by Sprecher et. al.)

By Joseph Stromberg
SMITHSONIANMAG.COM
JANUARY 14, 2014

Acquisition

Problems

Presentation Attack
Techniques to generate fake fingerprints:

- Paper printouts.
- Clay or latex molds, plus wood-glue, gelatin, or silicone mold filling.

Source: Dr. Adam Czajka

Objectives: spoofing and obfuscation.

Faking Fingerprints

Available at: https://www.youtube.com/watch?v=KdycMYILTr0

Acquisition

Problems

Presentation Attack
How robust might be the different sensors?

Capacitive, Pressure, and Thermal
May be fooled, if synthetic material presents similar skin properties.
Not enough resolution for level-3 features.

Optical
May be fooled, including paper printout.
Larger resolution will allow the use of level-3 features.

Acquisition

Problems

Presentation Attack
How robust might be the different sensors?

Ultrasound
May be robust if ultrasound penetration is used.

Touchless
Flat fake samples may not work due to 3D detection.

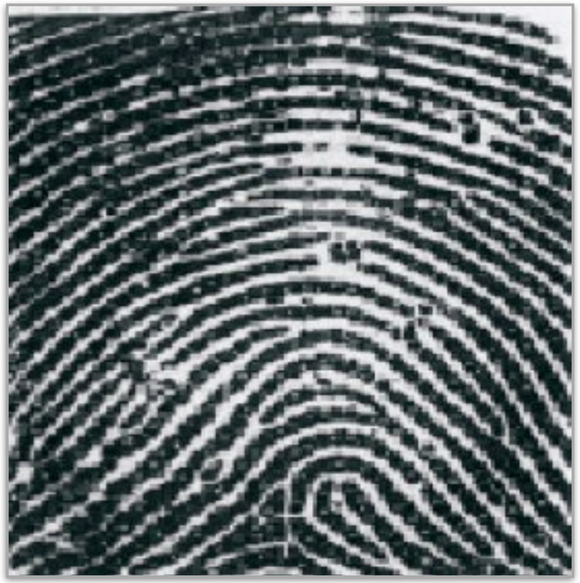
Acquisition

Problems

Presentation Attack
How about humans?

Fake or authentic?

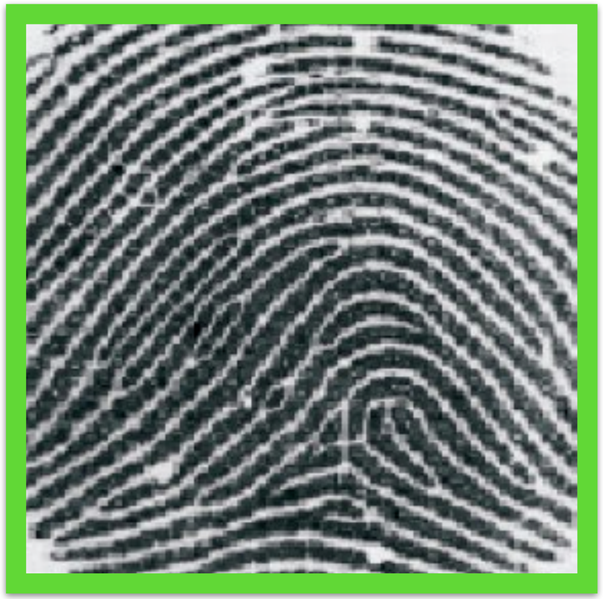
From capacitive sensor



Fake or authentic?

From capacitive sensor

Matsumoto, T.
Importance of Open Discussion on Adversarial Analyses for Mobile Security Technologies---A Case Study for User Identification---
ITU-T Workshop on Security, Seoul, 2002



authentic

gelatin

Fake or authentic?

From optical sensor

Fake or authentic?

From optical sensor

authentic

silicone

gelatin

Matsumoto, T.
Importance of Open Discussion on Adversarial Analyses for Mobile Security Technologies---A Case Study for User Identification---
ITU-T Workshop on Security, Seoul, 2002

Fake or authentic?

From optical sensor

Fake or authentic?

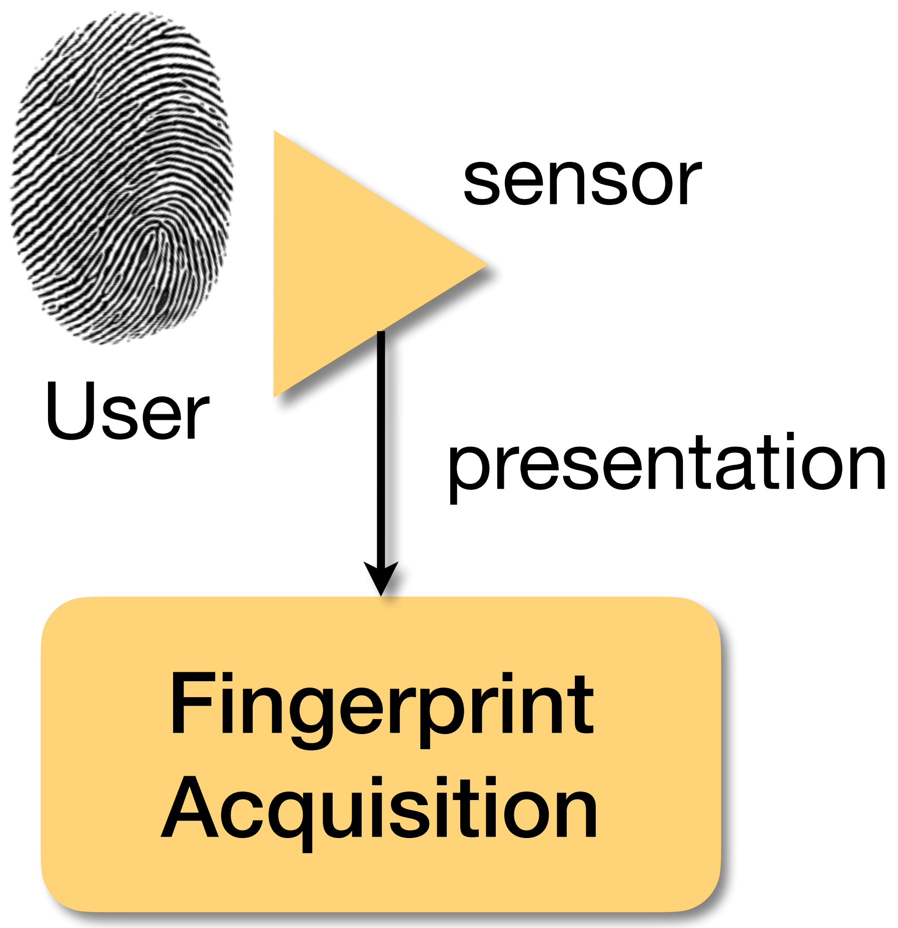
From optical sensor

Source: Dr. Adam Czajka

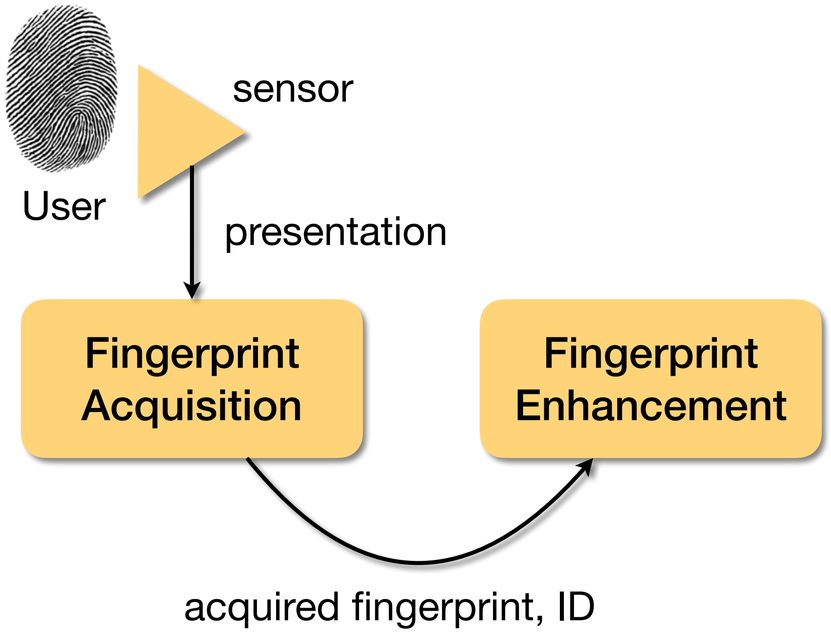
wood glue

authentic

Fingerprint Recognition



Fingerprint Recognition



Enhancement

Objectives
Noise removal.
Keep only essential information.
Reduce intra-class variation.

Why do we need to enhance?
Poor illumination conditions.
Careless fingerprint presentation.
Limited sensor accuracy.
Sensor dirtiness.
Skin condition.

Enhancement

Capture Condition

too bright

too dark

Enhancement

Skin Condition

Maltoni et al.
Handbook of Fingerprint Recognition
Springer Books, 2009

normal

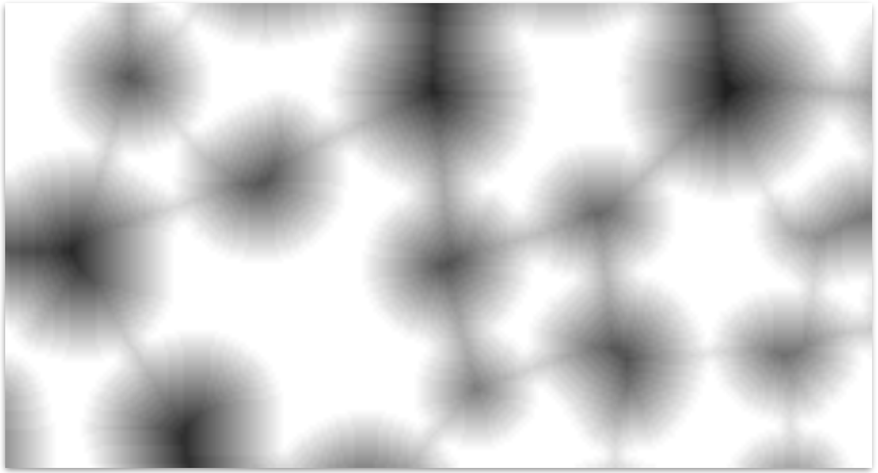
dry

wet

Enhancement

Image Processing Solutions

Tasks
Enhancement of image contrast.
Enhancement of ridges and valleys.
Content segmentation.
Others.



Enhancement

Image Processing Solutions

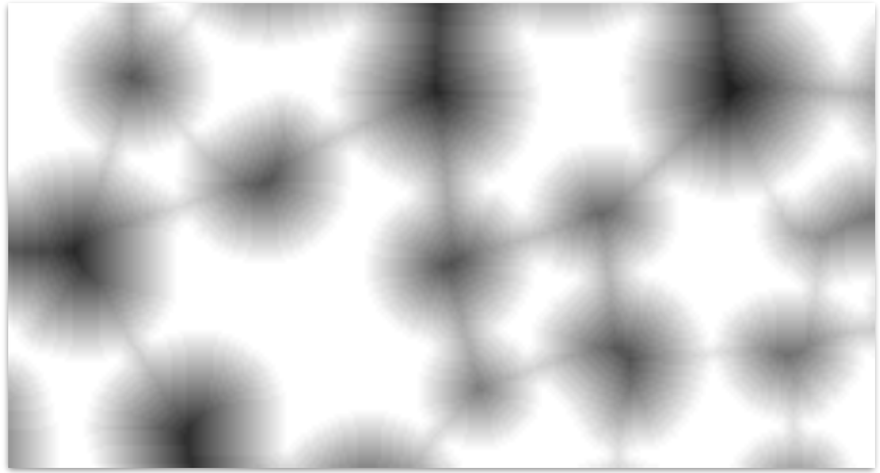
Tasks

Enhancement of image contrast.

Enhancement of ridges and valleys.

Content segmentation.

Others.

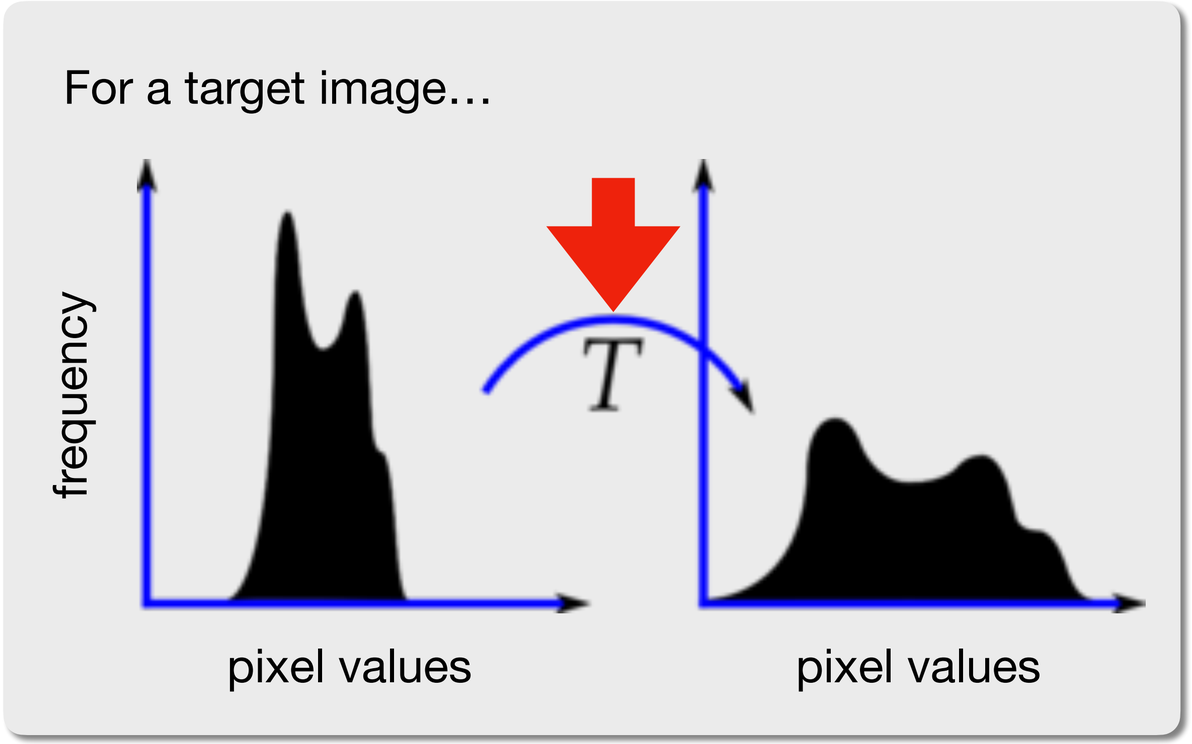


Enhancement

Image Contrast
Example:
Color histogram equalization.

Useful when pixel values are confined to a specific range (too bright or too dark images).

Stretching the color histogram will improve the contrast.

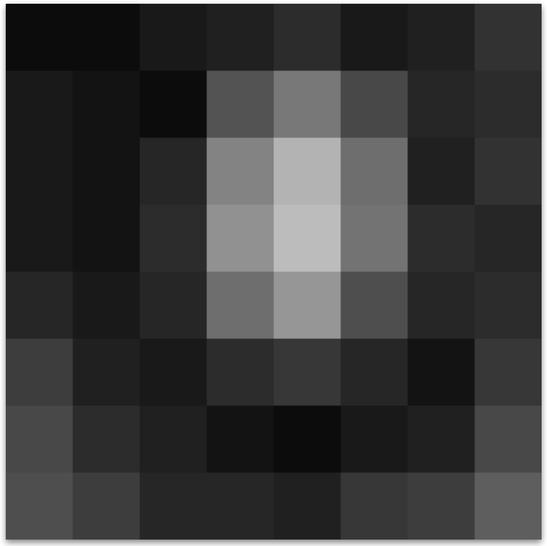


Enhancement

Color Histogram Equalization
Simple implementation

Toy Case

52	55	61	59	79	61	76	61
62	59	55	104	94	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90



Source: https://en.wikipedia.org/wiki/Histogram_equalization

Enhancement

Color Histogram Equalization
Simple implementation

Toy Case

1. Compute cumulative distribution function (CDF)

52	55	61	59	79	61	76	61
62	59	55	104	94	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

color histogram

Value	Count	Value	Count	Value	Count	Value	Count	Value	Count
52	1	64	2	72	1	85	2	113	1
55	3	65	3	73	2	87	1	122	1
58	2	66	2	75	1	88	1	126	1
59	3	67	1	76	1	90	1	144	1
60	1	68	5	77	1	94	1	154	1
61	4	69	3	78	1	104	2		
62	1	70	4	79	2	106	1		
63	2	71	2	83	1	109	1		

Source: https://en.wikipedia.org/wiki/Histogram_equalization

Enhancement

Color Histogram Equalization
Simple implementation

Toy Case

1. Compute cumulative distribution function (CDF)

52	55	61	59	79	61	76	61
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67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

v, Pixel Intensity	cdf(v)
52	1
55	4
58	6
59	9
60	10
61	14
62	15
63	17
64	19

Source: https://en.wikipedia.org/wiki/Histogram_equalization

Enhancement

Color Histogram Equalization
Simple implementation

Toy Case

1. Compute cumulative distribution function (CDF)

2. Perform min-max normalization
[0, 255] interval

52	55	61	59	79	61	76	61
62	59	55	104	94	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

v, Pixel Intensity	cdf(v)	h(v), Equalized v
52	1	0
55	4	12
58	6	20
59	9	32
60	10	36
...		
144	63	251
154	64	255

Source: https://en.wikipedia.org/wiki/Histogram_equalization

Enhancement

Color Histogram Equalization
Simple implementation

Toy Case

1. Compute cumulative distribution function (CDF)

2. Perform min-max normalization
[0, 255] interval

52	55	61	59	79	61	76	61
62	59	55	104	94	85	59	71
63	65	66	113	144	104	63	72
64	70	70	126	154	109	71	69
67	73	68	106	122	88	68	68
68	79	60	70	77	66	58	75
69	85	64	58	55	61	65	83
70	87	69	68	65	73	78	90

0	12	53	32	190	53	174	53
57	32	12	227	219	202	32	154
65	85	93	239	251	227	65	158
73	146	146	247	255	235	154	130
97	166	117	231	243	210	117	117
117	190	36	146	178	93	20	170
130	202	73	20	12	53	85	194
146	206	130	117	85	166	182	215

Source: https://en.wikipedia.org/wiki/Histogram_equalization

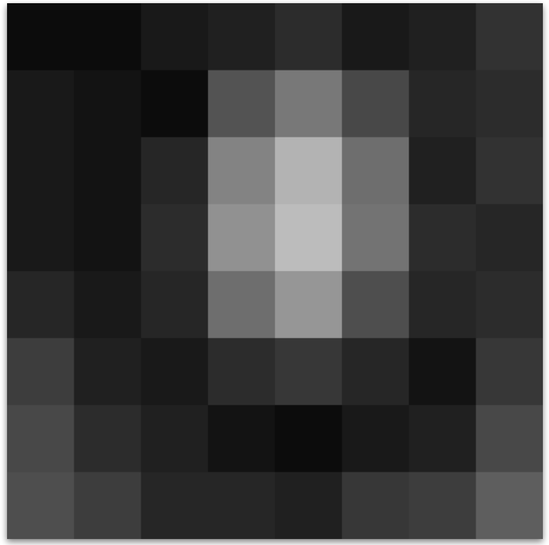
Enhancement

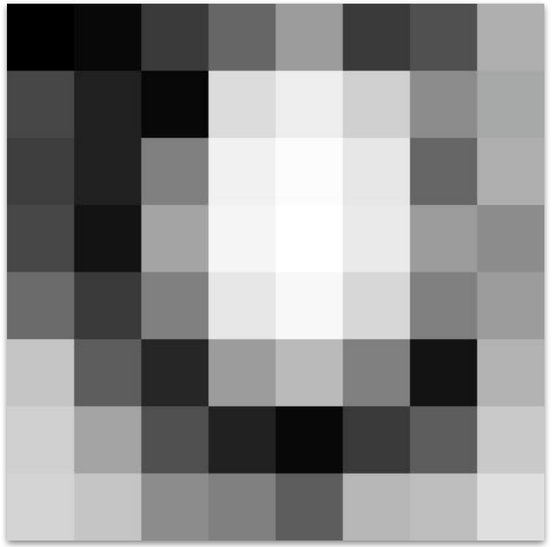
Color Histogram Equalization
Simple implementation

Toy Case

1. Compute cumulative distribution function (CDF)

2. Perform min-max normalization
[0, 255] interval





Source: https://en.wikipedia.org/wiki/Histogram_equalization

Enhancement

Image Contrast
Example:
Color histogram equalization.

Example: too bright capture.

before

after

Enhancement

Image Contrast
Example:
Color histogram equalization.

Example: too dark capture.

before

after

Enhancement

Image Processing Solutions

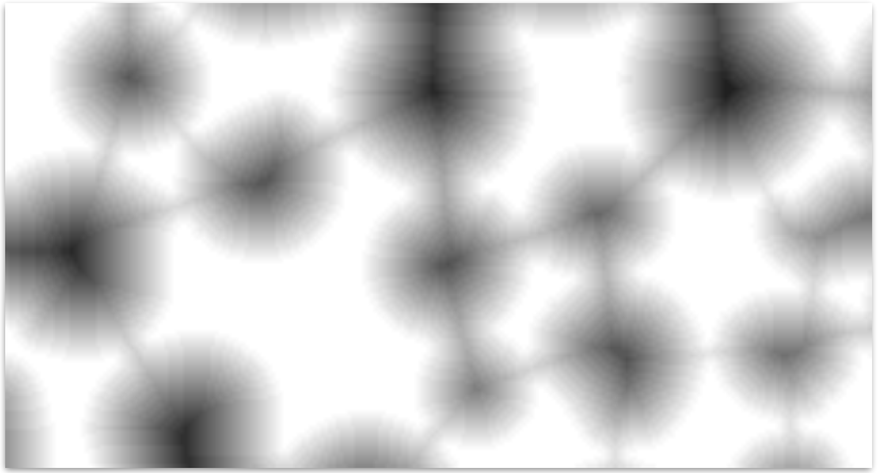
Tasks

Enhancement of image contrast.

Enhancement of ridges and valleys.

Content segmentation.

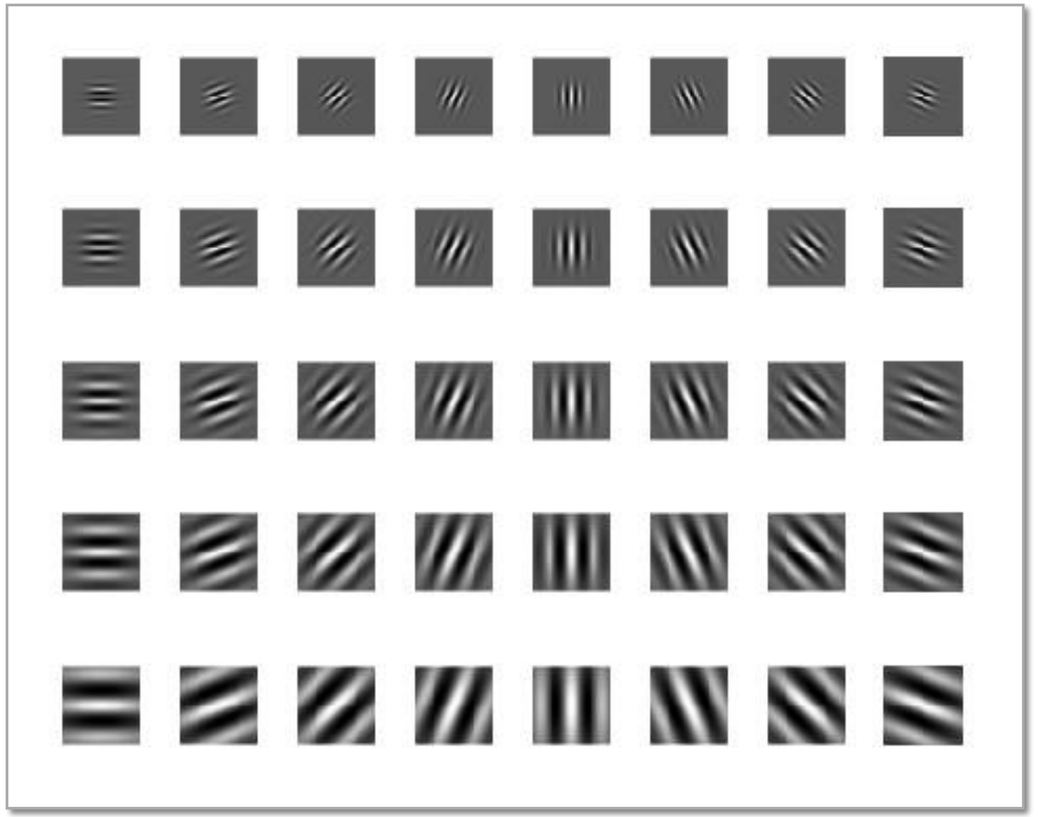
Others.



Enhancement

Ridges and Valleys
Example:
Image filtering with
Gabor filters.

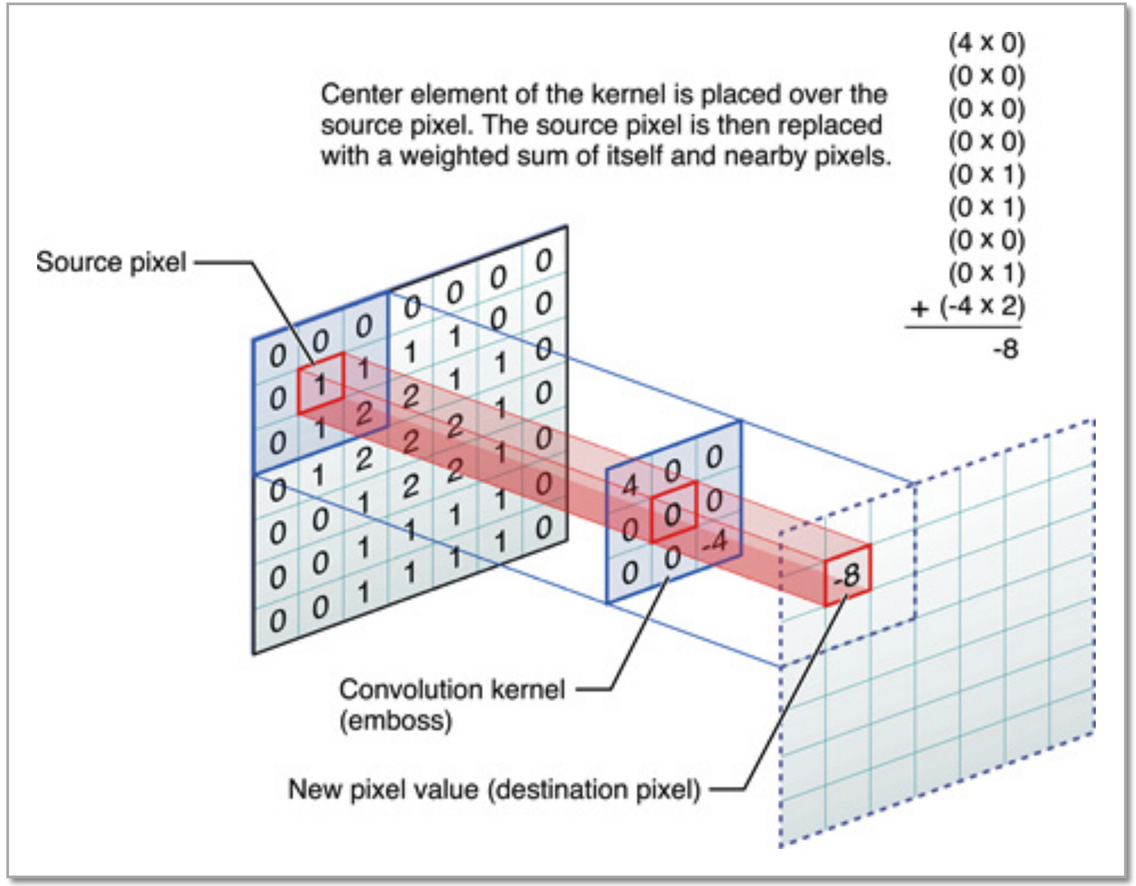
Ridges and valleys may become more prominent when a fingerprint image is filtered by Gabor filters.



Enhancement

Ridges and Valleys
Example:
Image filtering with Gabor filters.

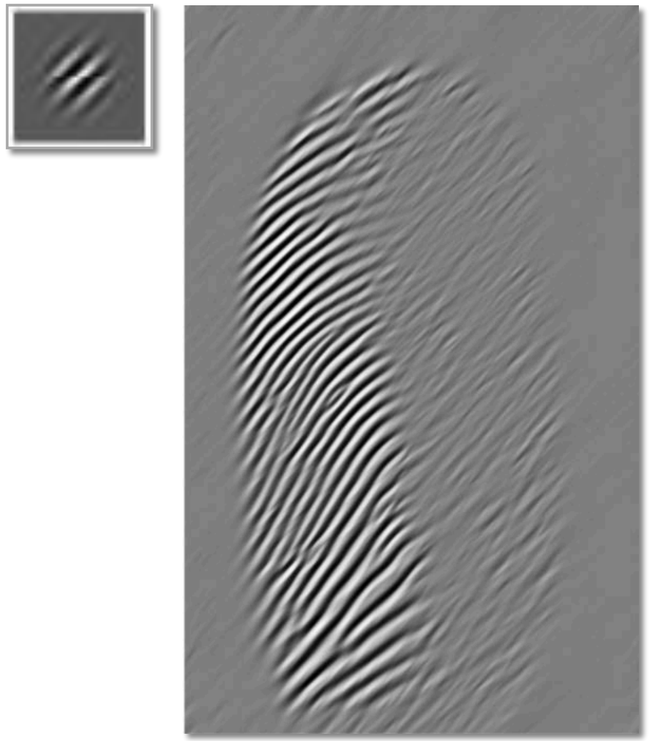
Gabor filters may be applied to an image through convolutions.

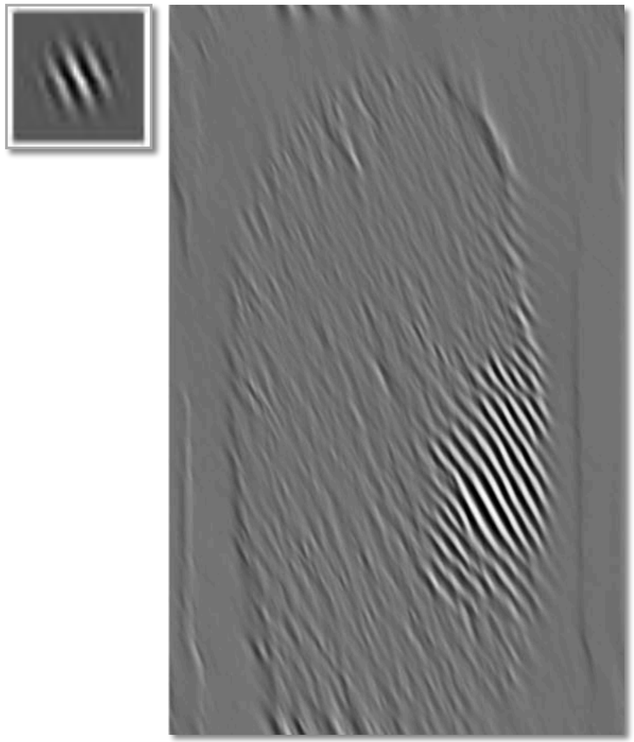


Source:https://developer.apple.com/library/archive/documentation/Performance/Conceptual/vImage/ConvolutionOperations/ConvolutionOperations.html

Enhancement

Ridges and Valleys
Example:
Image filtering with
Gabor filters.





Enhancement

Ridges and Valleys
Example:
Image filtering with
Gabor filters.

Maltoni et al.
Handbook of Fingerprint Recognition
Springer Books, 2009

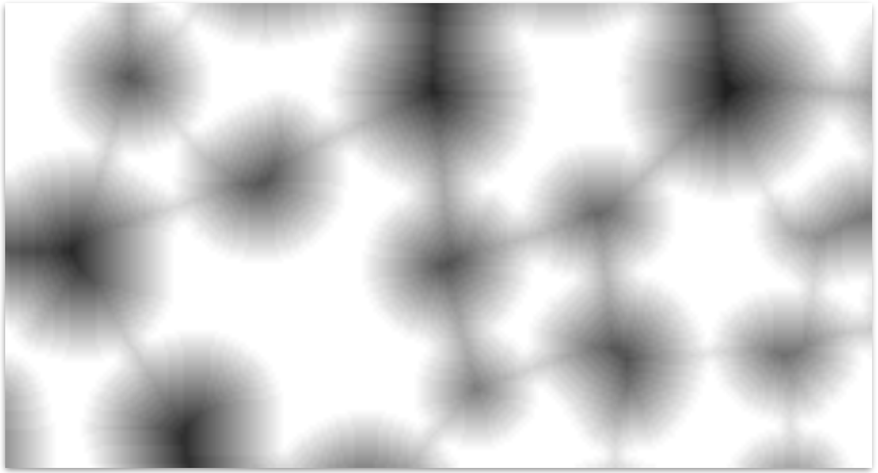
before

after

Enhancement

Image Processing Solutions

Tasks
Enhancement of image contrast.
Enhancement of ridges and valleys.
Content segmentation.
Others.

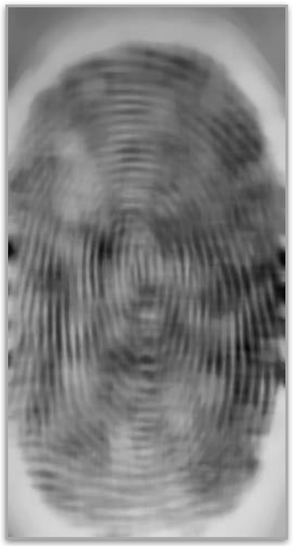


Enhancement

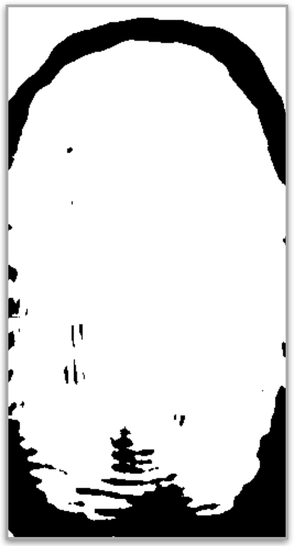
Segmentation

Example: blurring, thresholding, and morphological operations.

before



blur



threshold

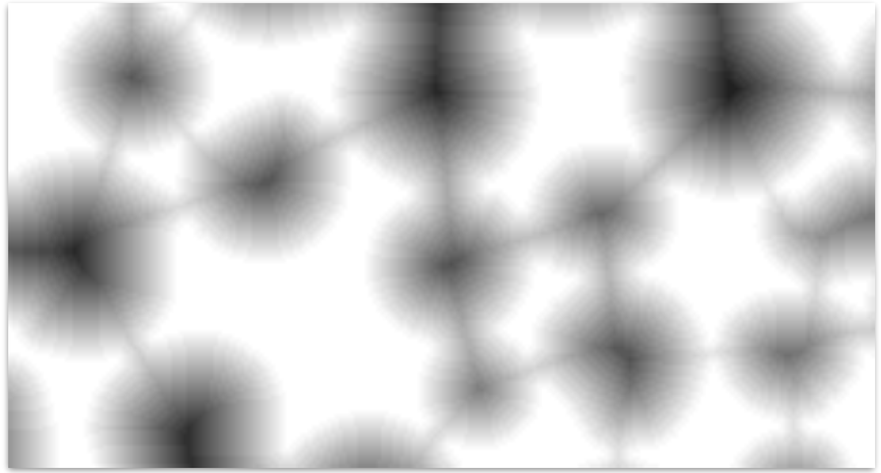
open

after

Enhancement

Image Processing Solutions

Tasks
Enhancement of image contrast.
Enhancement of ridges and valleys.
Content segmentation.
Others.

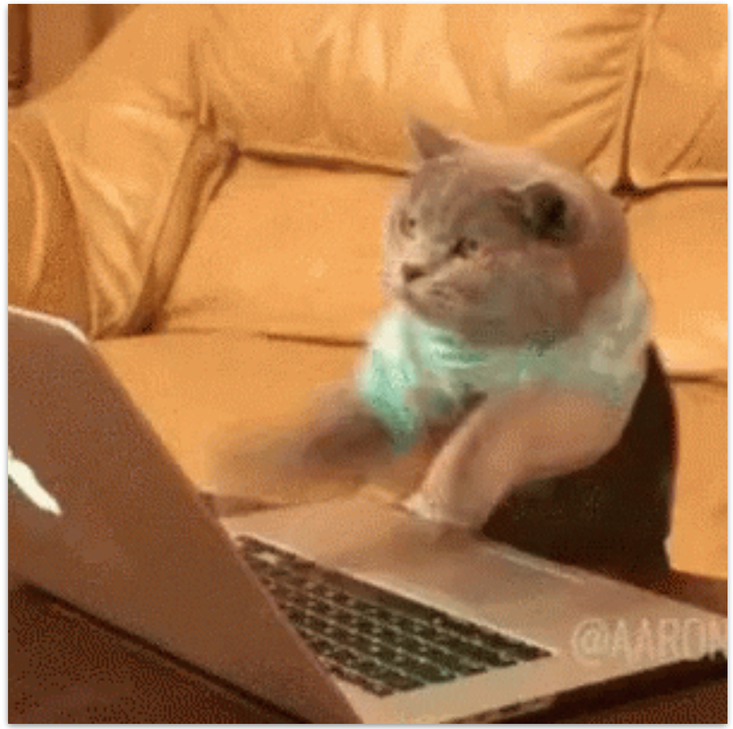


Enhancement

Image Processing Solutions

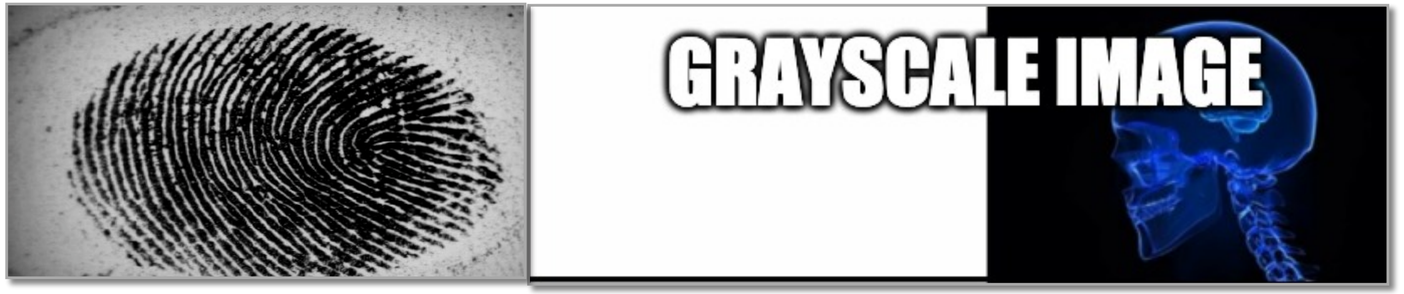
Be Aware
Besides the aforementioned techniques, there are much more sophisticated and effective ones.

We'll see some of them in practice and with more details during our next coding class.



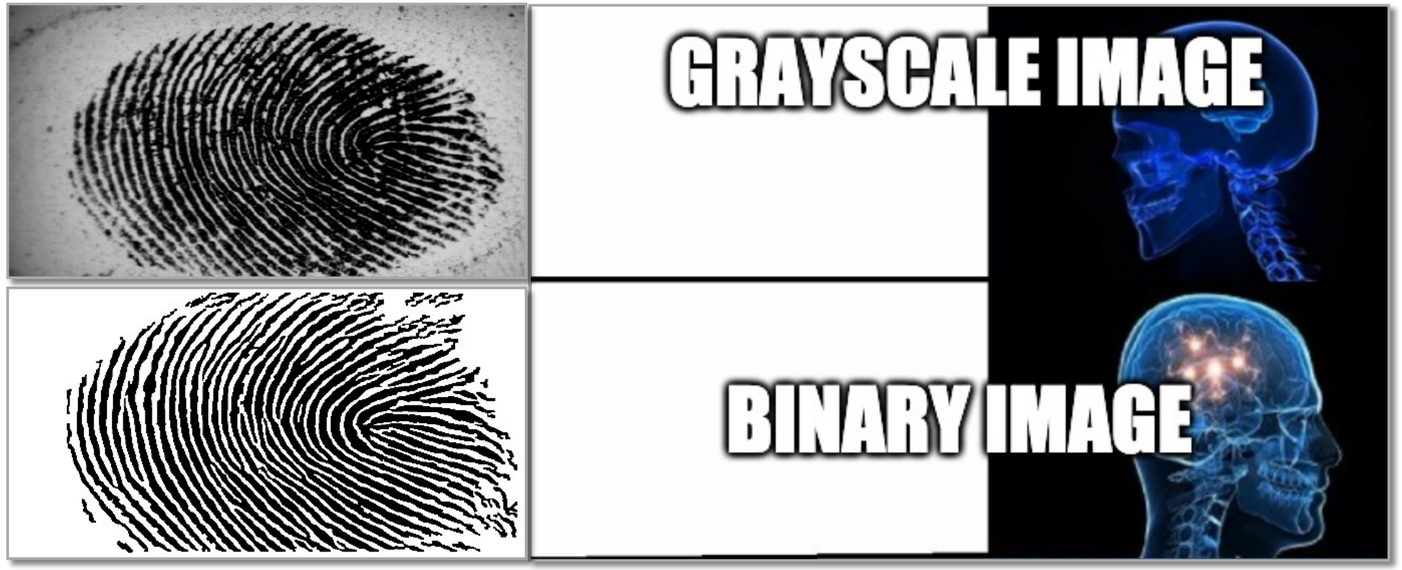
Enhancement

Other Strategies
Start from…



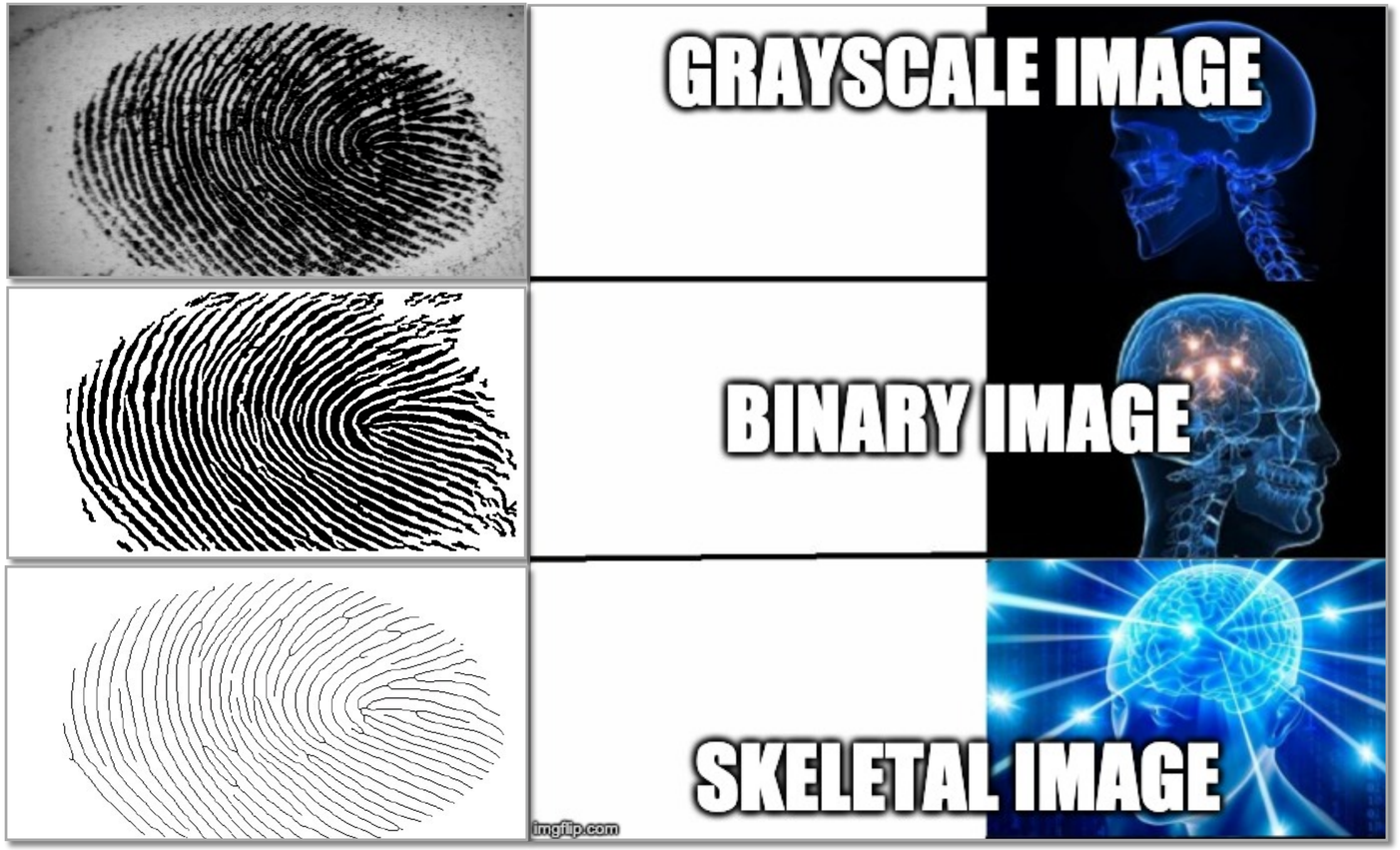
Enhancement

Other Strategies
Start from…



Enhancement

Other Strategies
Start from…



Source: Dr. Adam Czajka

Enhancement

Other Strategies
Start from…

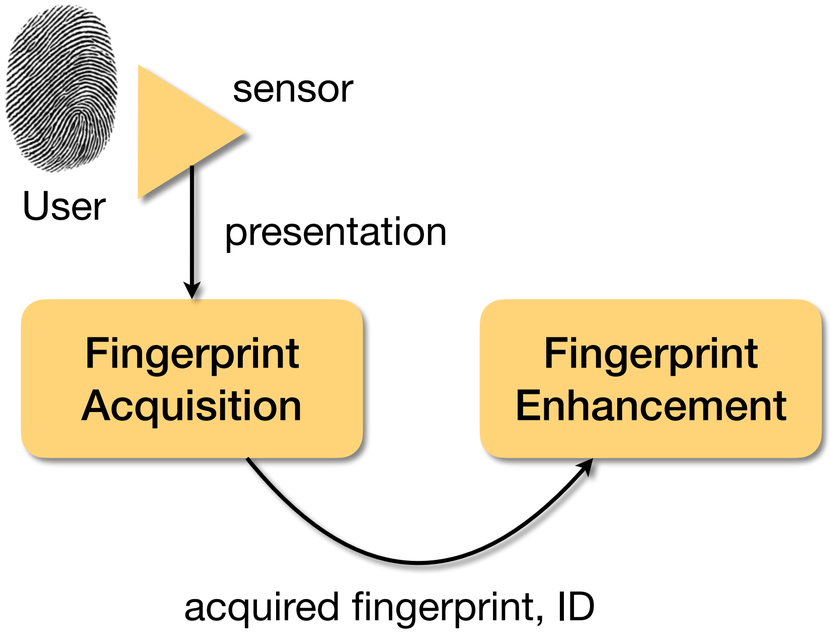
Each strategy has its own set of pros and cons, and will lead to different performance.

Source: Dr. Adam Czajka

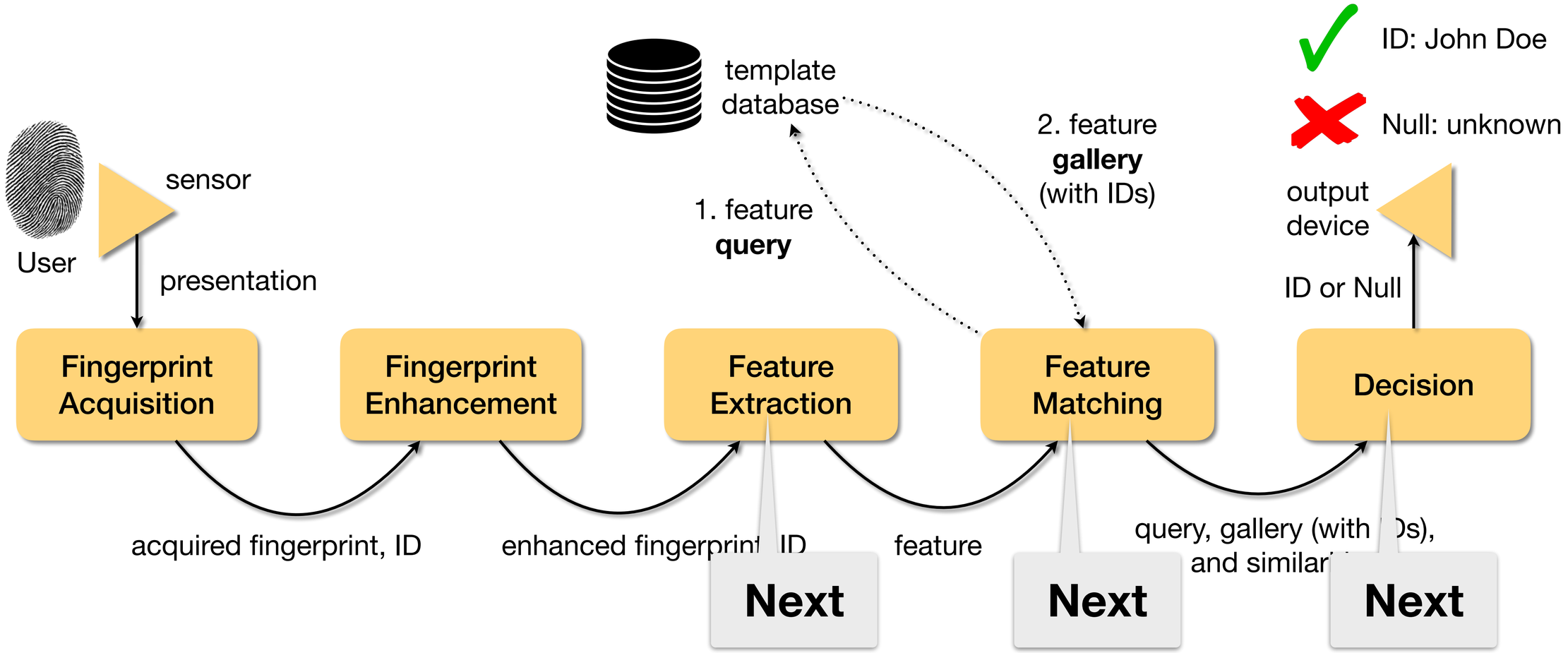
Enhancement

Source: Dr. Adam Czajka

Fingerprint Recognition



Fingerprint Recognition



What's Next?

Even more about fingerprints
Fingerprint feature extraction methods.
Fingerprint matching methods.

Fill out your *Today-I-missed* Statement
Please visit sakai.luc.edu/x/BCJs8K.