Fingerprint Recognition III

COMP 388-002/488-002 Biometrics

Daniel Moreira

Fall 2025

LOYOLA UNIVERSITY CHICAGO

Today we will…

Get to know
Minutiae detection, description, and matching.

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Today's Attendance

Please fill out the form

forms.gle/MZ44nZoCkijd3fhn7

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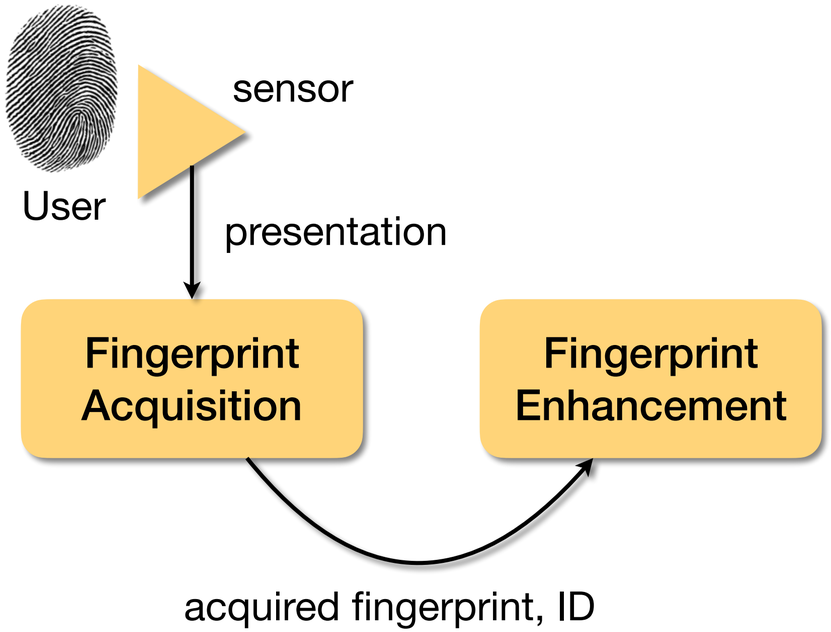
Fingerprint Recognition



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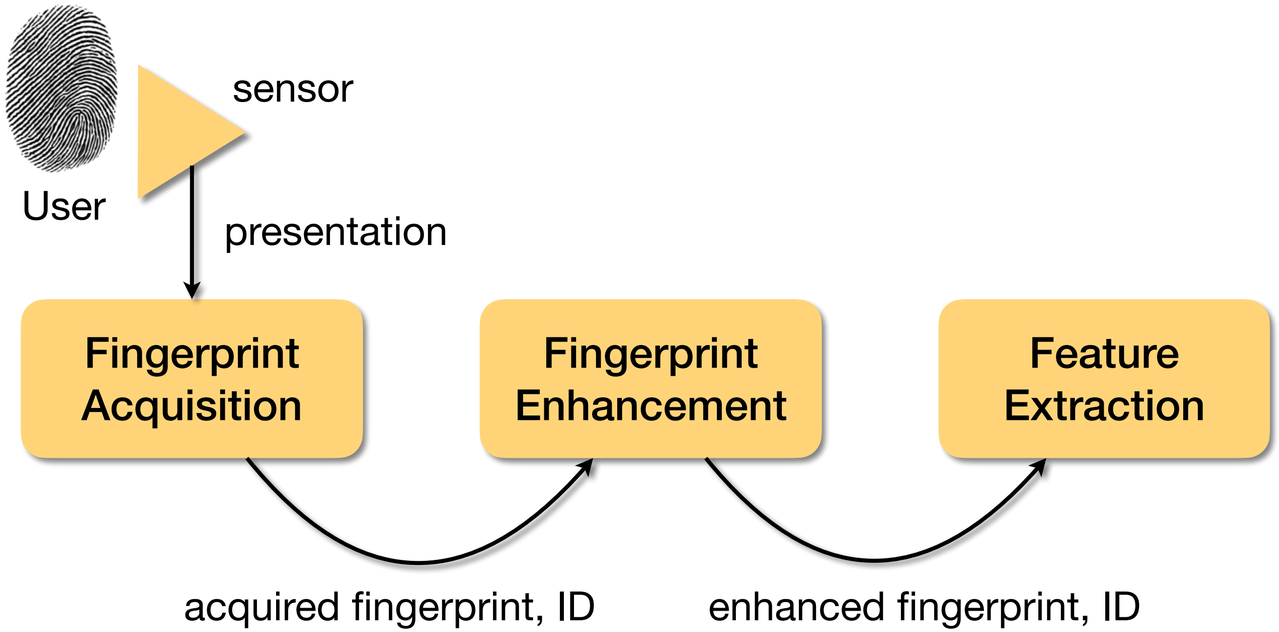
Fingerprint Recognition



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Feature Extraction

Three Levels of Features

From coarse to fine:

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

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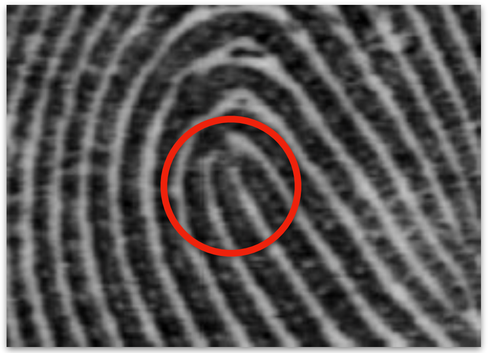
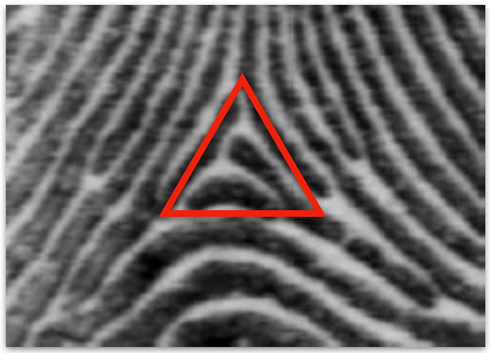
Feature Extraction

Level-1 Features
Singular points and core.
Recommended capture resolution: 250 ppi (pixels per inch).
Useful for fingerprint classification, indexing, and alignment.

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.

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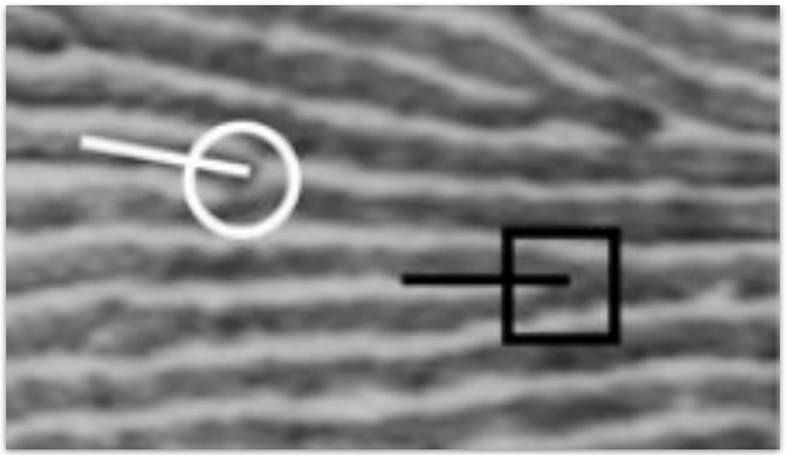
Features

Level-2 Features
Minutiae (Galton's details).
Recommended capture resolution: 500 ppi.
Useful for fingerprint matching.

Ridge Ending  Ridge Bifurcation

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

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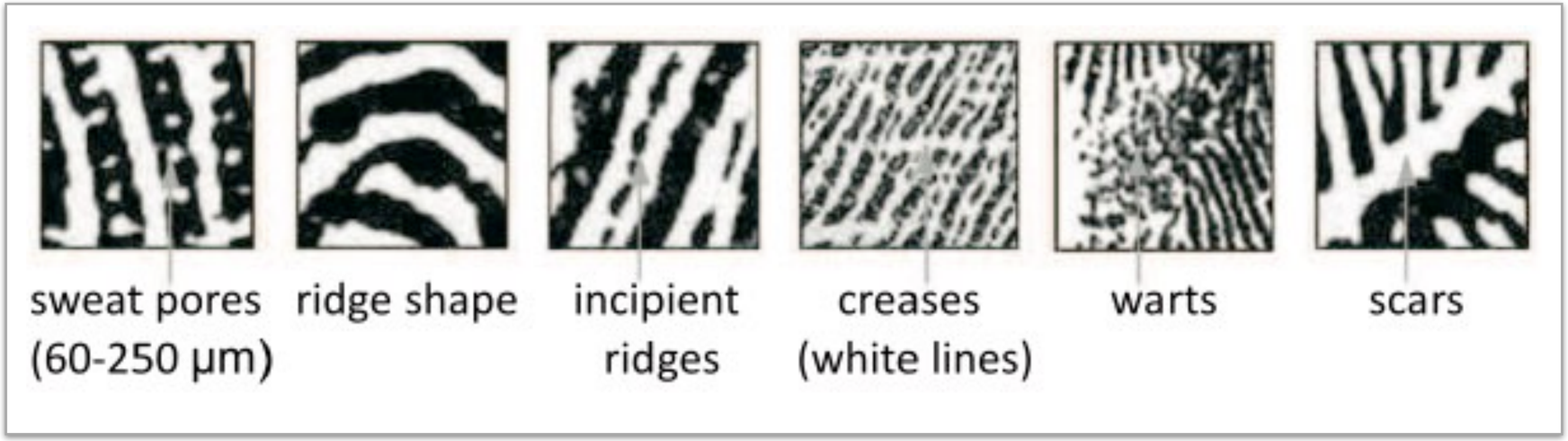
Features

Level-3 Features

Sweat pores, ridge shape, and lifetime acquired marks.

Recommended capture resolution: 1000 ppi.

Useful for liveness and spoofing detection.



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

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Feature Extraction

Three Levels of Features

From coarse to fine:

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

Let’s dive into it…

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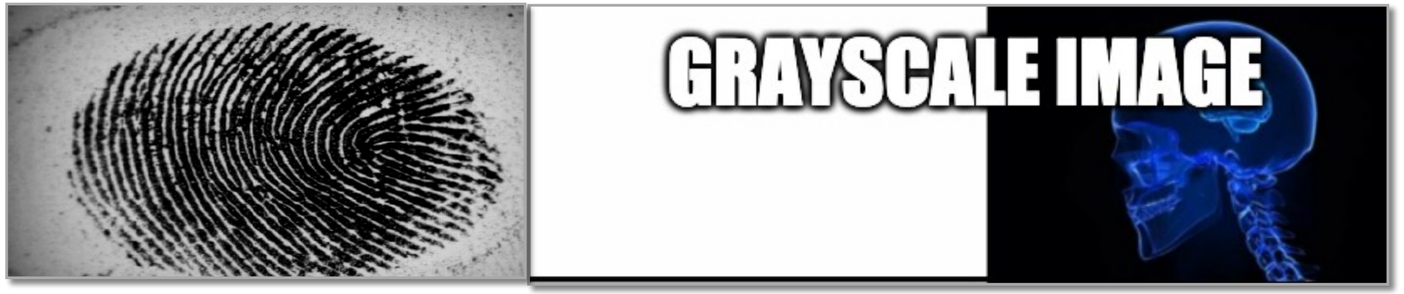
Minutiae Detection

Three Stages
Start from…



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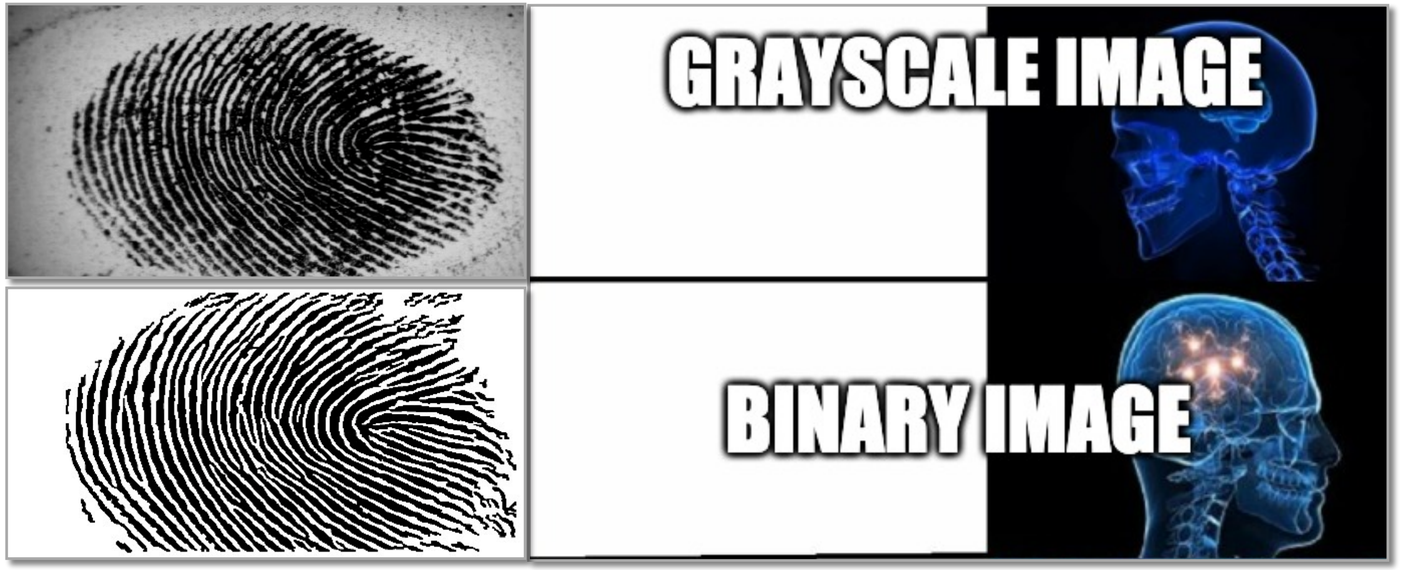
Minutiae Detection

Three Stages
Start from…



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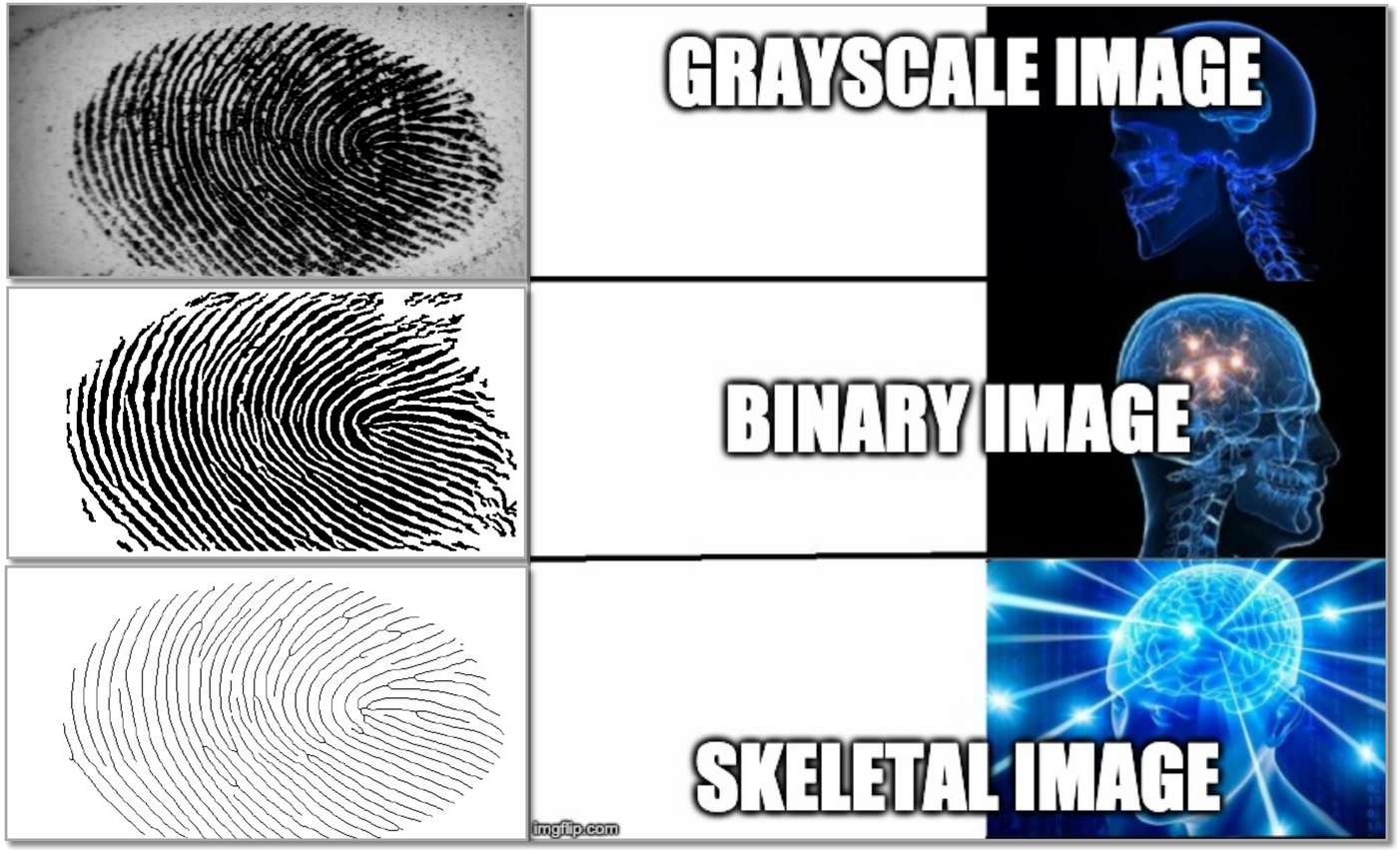
Minutiae Detection

Three Stages
Start from…



Source: Dr. Adam Czajka

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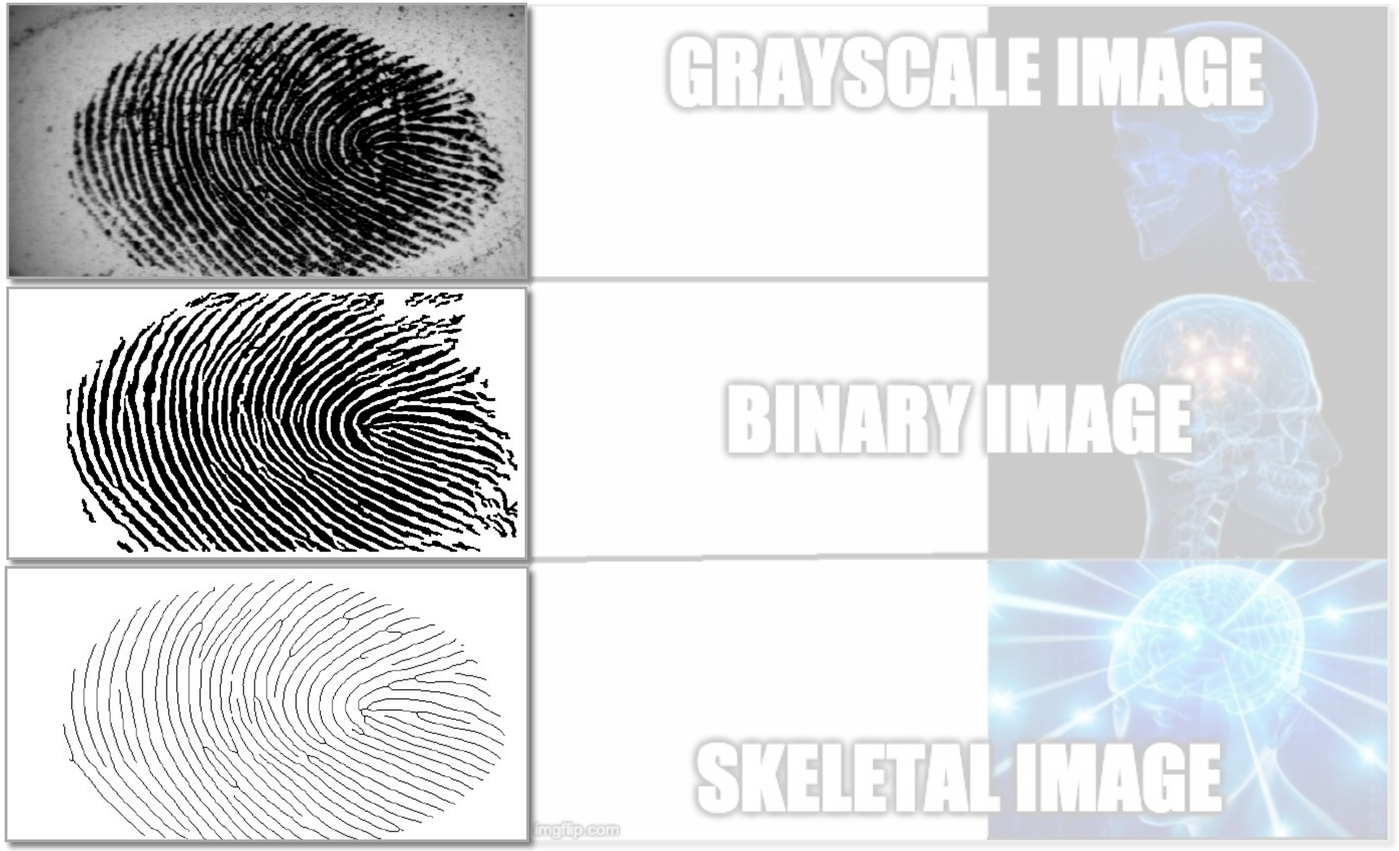
Minutiae Detection

Three Stages
Start from…

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



Source: Dr. Adam Czajka

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Minutiae Detection

Grayscale Images
Need for only basic enhancement (e.g., contrast improvement).

Source: Dr. Adam Czajka

Solution Examples

Classification of Gabor filters' response
Fingerprint image processing using neural networks
IEEE TENCON, 1990

Ridge tracking
Maio and Maltoni
Direct Gray-Scale Minutiae Detection In Fingerprints
IEEE T.PAMI, 1997

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Minutiae Detection

Source: Dr. Adam Czajka

Binary Images

Need for binarization enhancement.

Ridge tracking becomes easier.

How to perform binarization?

Image Processing

Ridge and valley enhancement, through the application of Gabor filters, followed by filter response thresholding.

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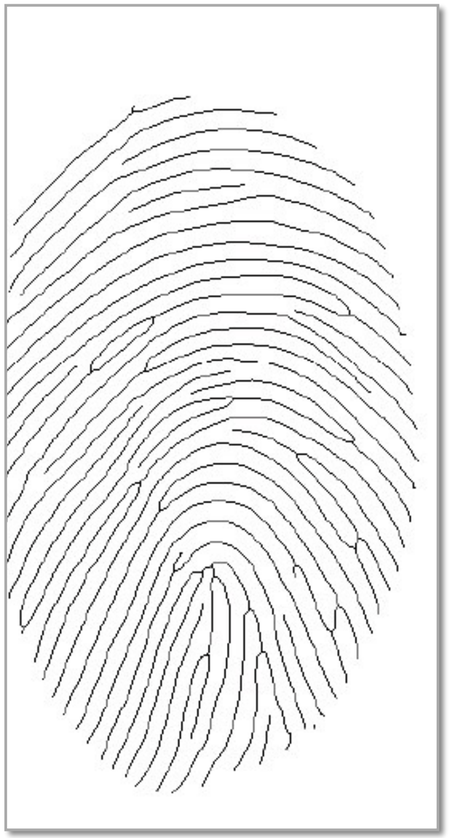
Minutiae Detection

Source: Dr. Adam Czajka



Skeletal Images
Need for binarization enhancement
followed by skeletonization enhancement.

How to perform skeletonization?

Image Processing
After binarization, apply sequences of morphological operations, such as erosion.

Source: https://scikit-image.org/docs/dev/auto_examples/edges/plot_skeleton.html

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Minutiae Detection

Three Strategies

Source: Dr. Adam Czajka

Let’s dive into it…

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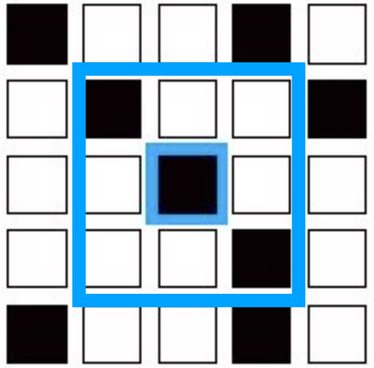
Minutiae Detection

Skeletal Images

Analyze each ridge pixel neighborhood.

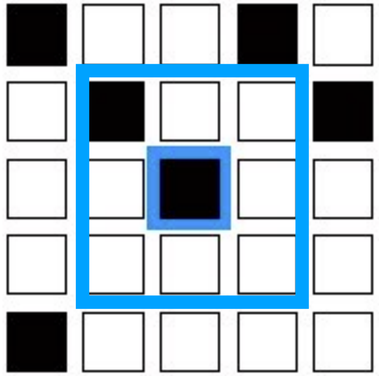
Count the number of ridge pixels (*#RP*).

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



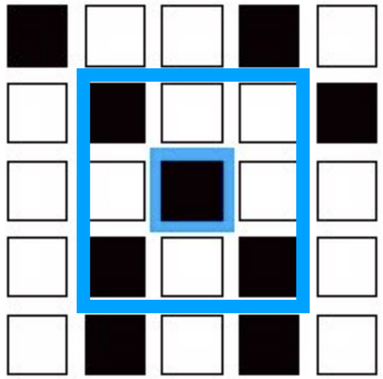
#RP = 3

No minutiae



#RP < 3

Ridge end



#RP > 3

Ridge bifurcation

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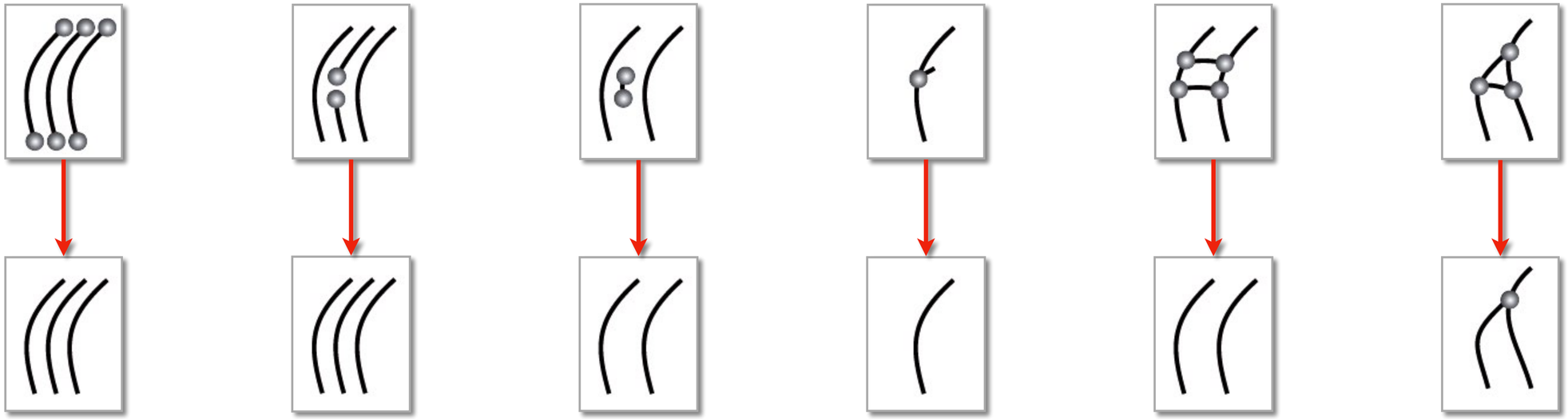
Minutiae Detection

Skeletal Images
Remove false positive minutiae.
Example Heuristics:

Source: Dr. Adam Czajka



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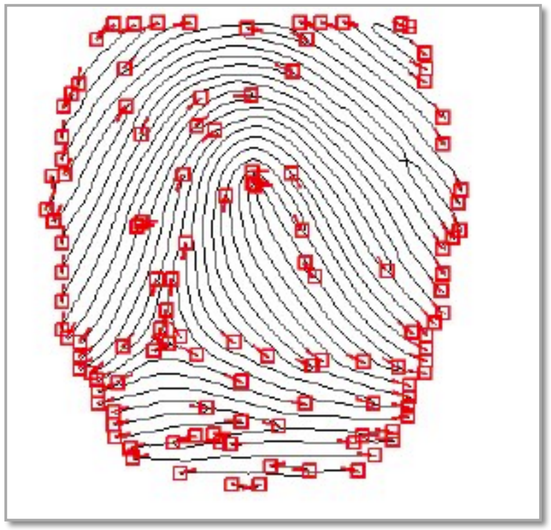
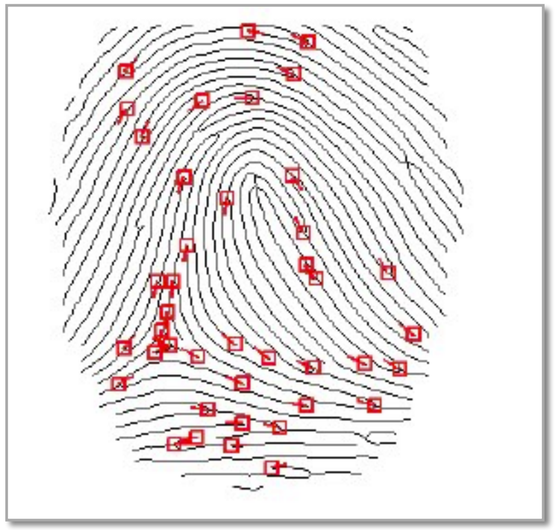
Minutiae Detection

Skeletal Images

Remove false positive minutiae.



before



after

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

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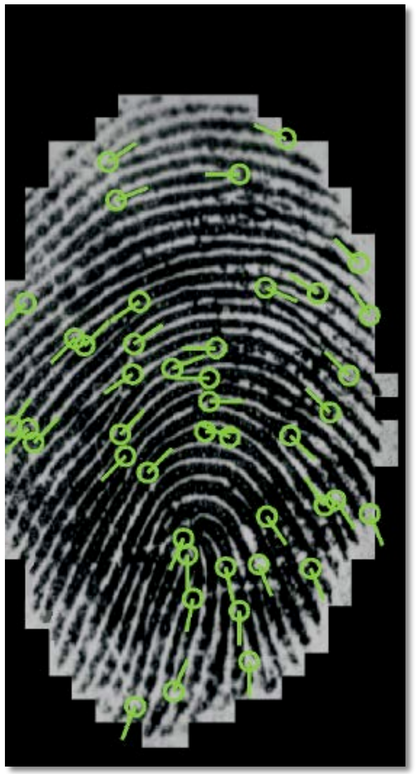
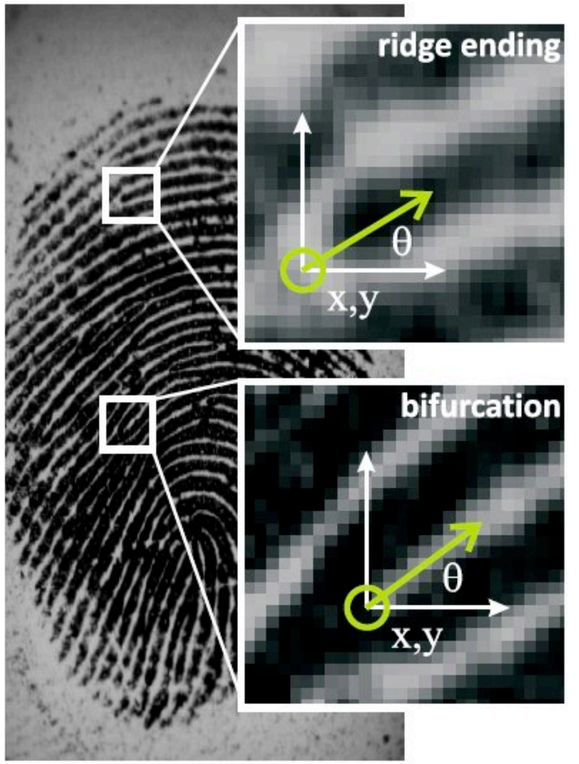
Minutiae Description

ISO/IEC FDIS 19794-2 (2011)
For each minutiae,
store position (x, y) and
angle θ.

Possible extra information:
Minutiae type (either ridge end or bifurcation).



Source: Dr. Adam Czajka



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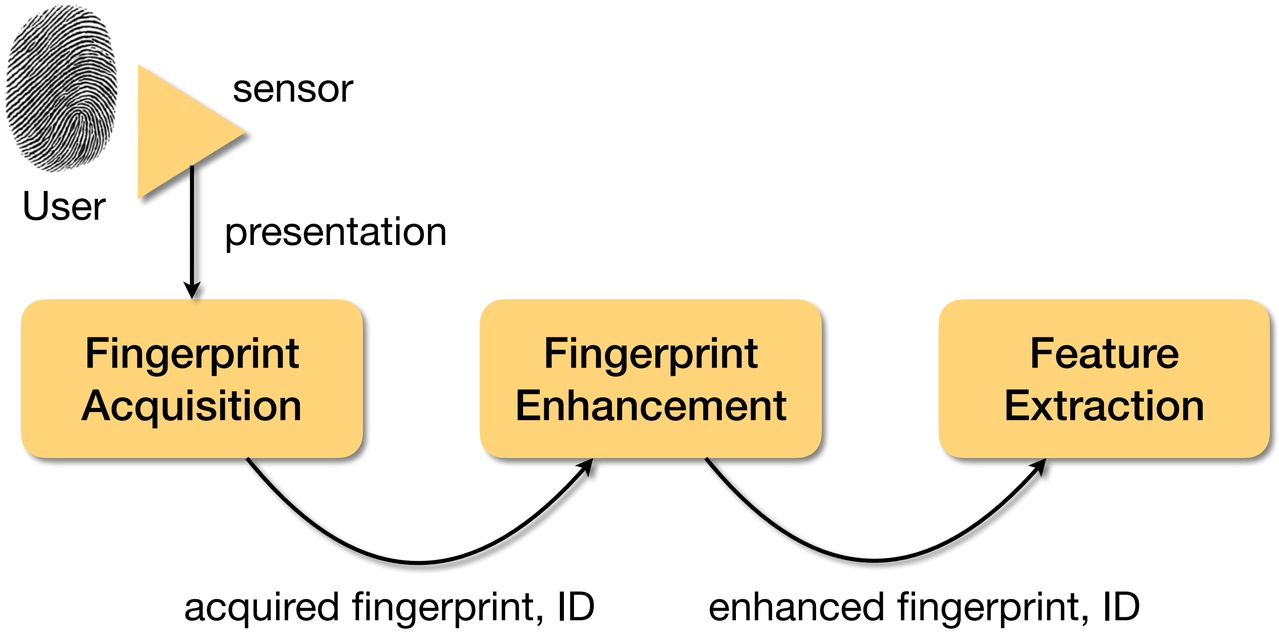
Fingerprint Recognition



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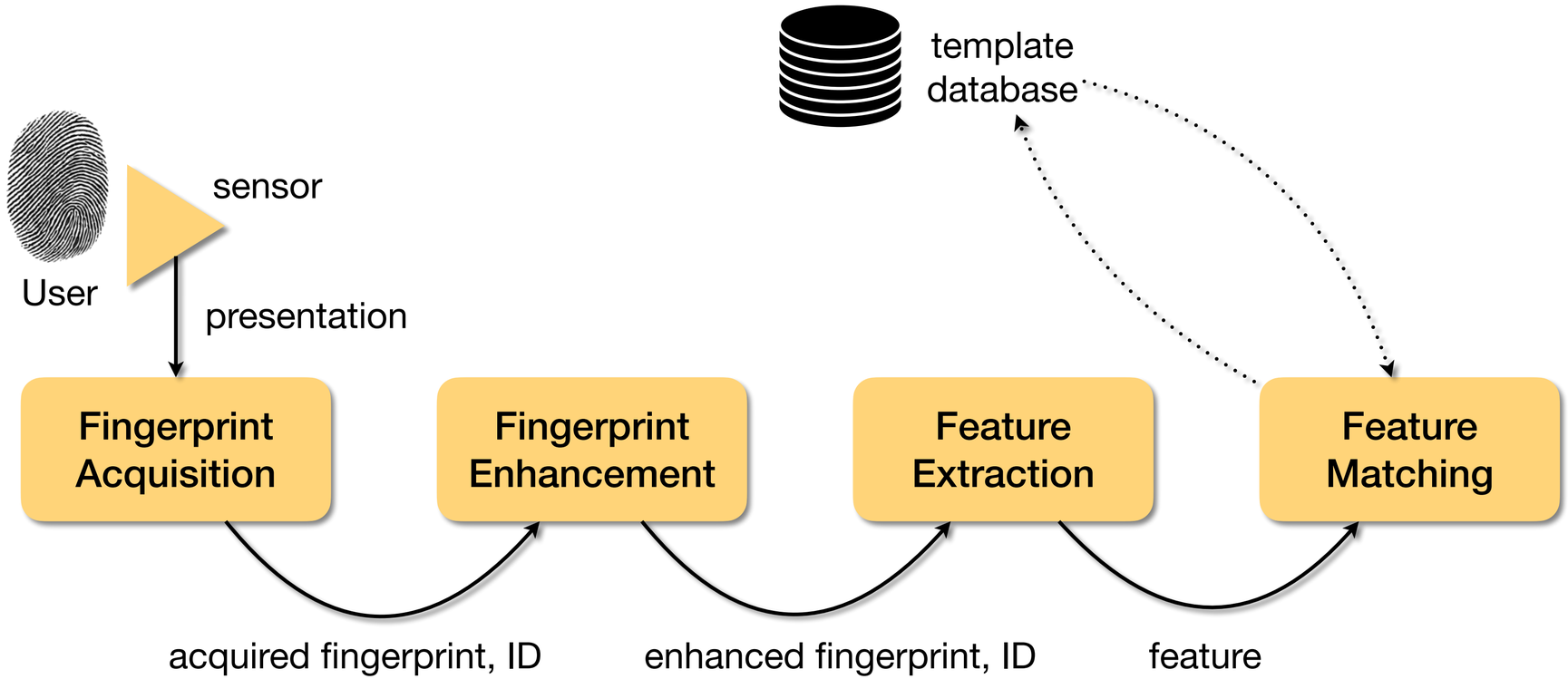

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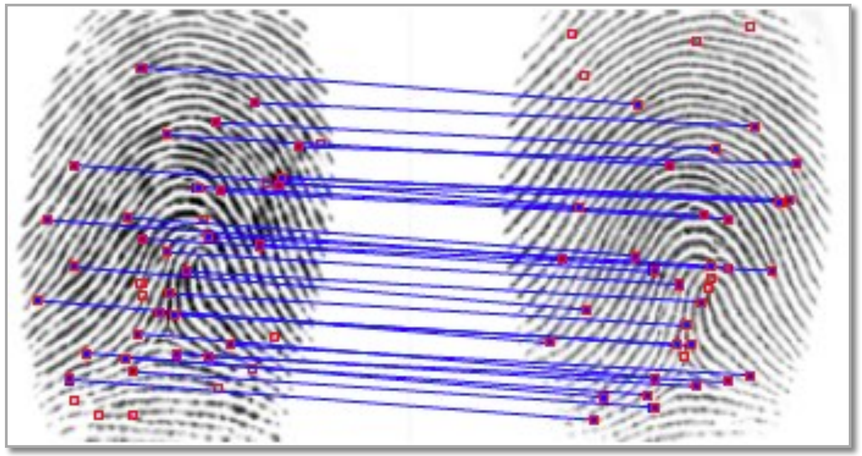
Feature Matching

How to establish pairs of corresponding minutiae between two samples?

Check for agreements between both (x, y) **positions** and θ **angles**.



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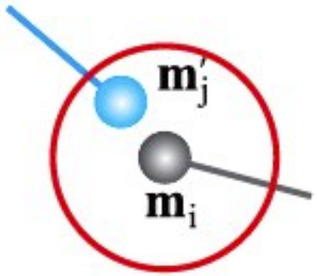
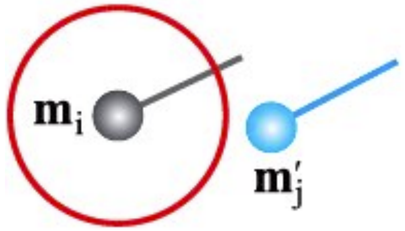
Springer Books, 2011



✗ Positions agree, but angles do not.



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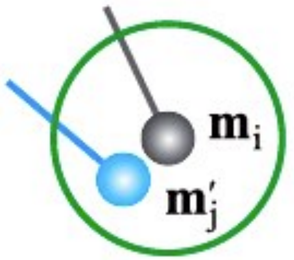

✓ Both angles and positions agree.

m_i : i-th minutiae from image i.
m'_j : j-th minutiae from image j.
Source: Dr. Adam Czajka

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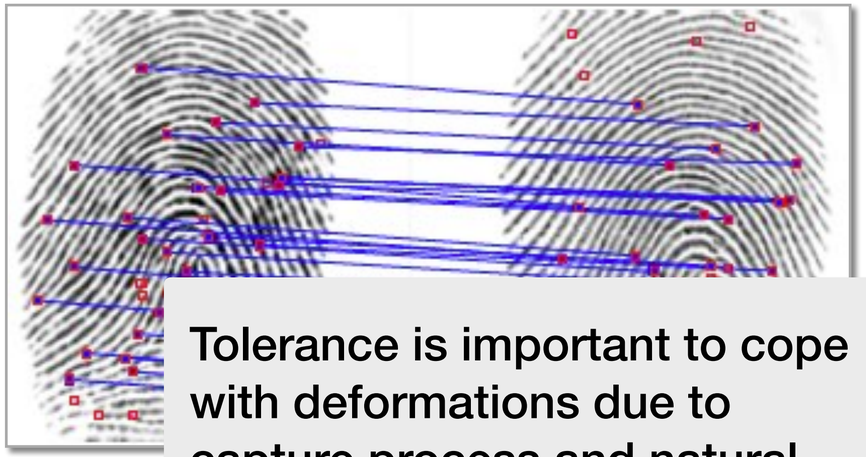
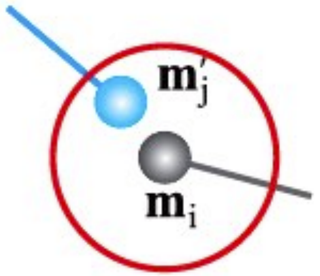
Feature Matching

How to establish pairs of corresponding minutiae between two samples?

Check for agreements between both (x, y) **positions** and θ **angles**.



Tolerance is important to cope with deformations due to capture process and natural skin deformations.



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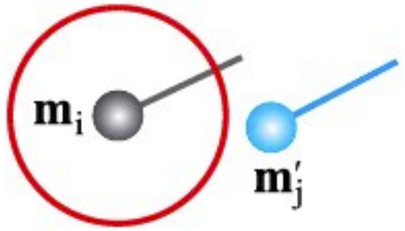

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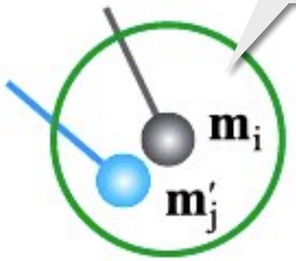

✓ Both angles and positions agree.

m_i : i-th minutiae from image i.
m'_j : j-th minutiae from image j.
Source: Dr. Adam Czajka

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Feature Matching

Hough Transform
Objective: find scale, rotation, and translation transformations that maximize the number of agreeing minutiae (a.k.a, **matches**).

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

query

template

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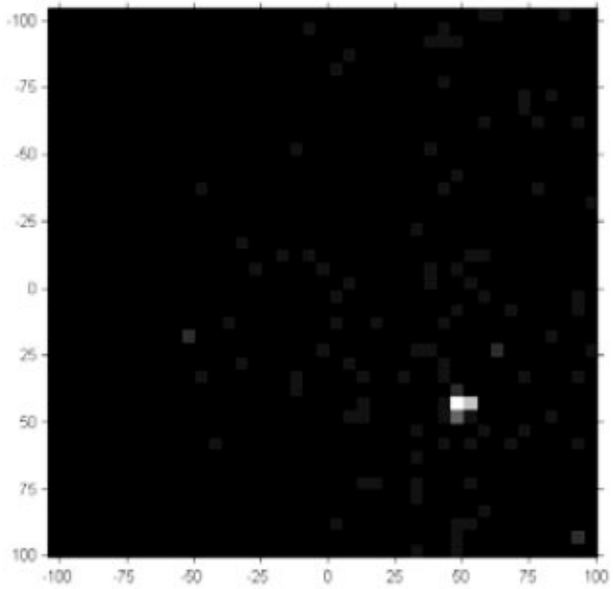
Feature Matching

Hough Transform
Solution: define the **Hough Space** -
a space with all the meaningful
(scale, rotation, translation) solutions.
Take the sample from the space
that maximizes the number of matches.

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



Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

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Feature Matching

Hough Transform

query

Jain, Ross, and Nadakumar
Introduction to Biometrics
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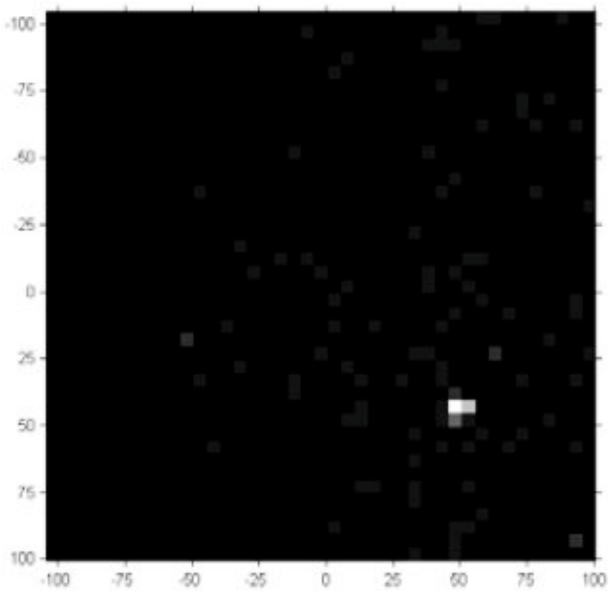

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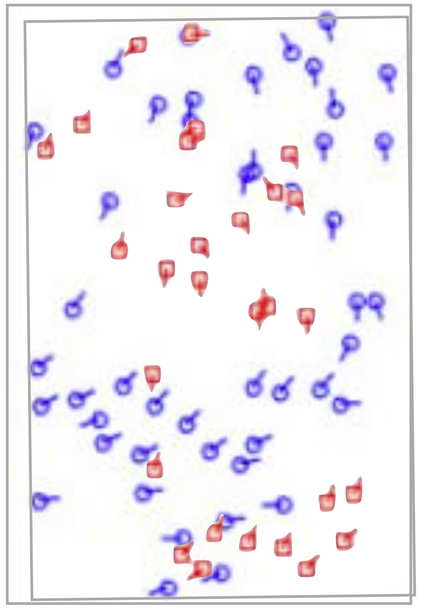
Feature Matching

Hough Transform

template



query

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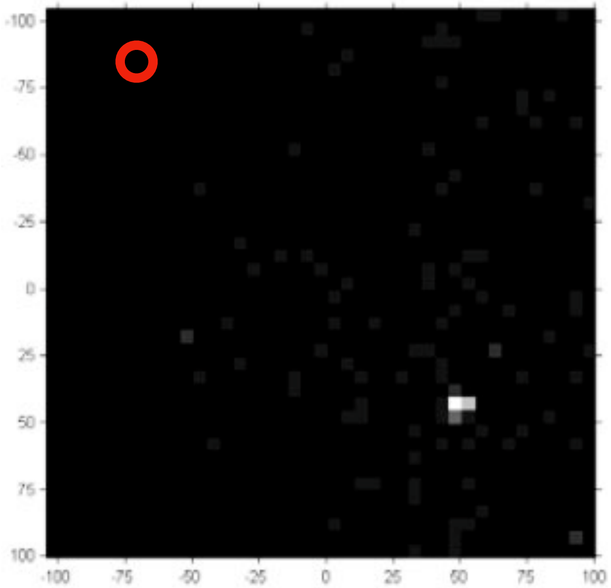
Springer Books, 2011



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Feature Matching

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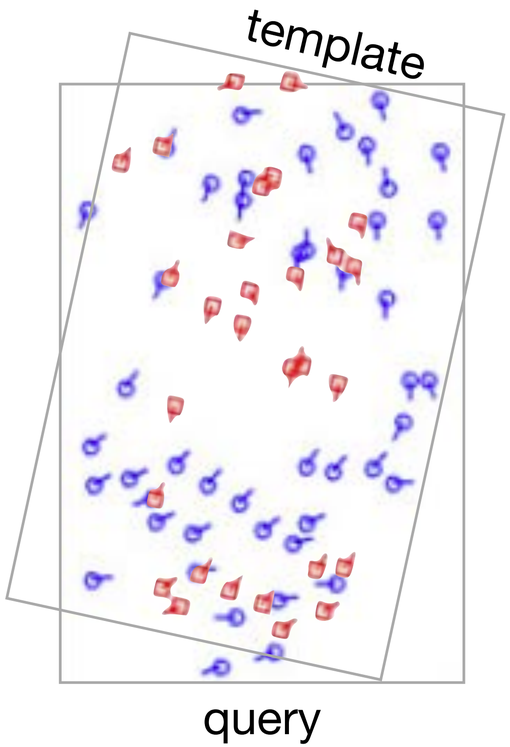

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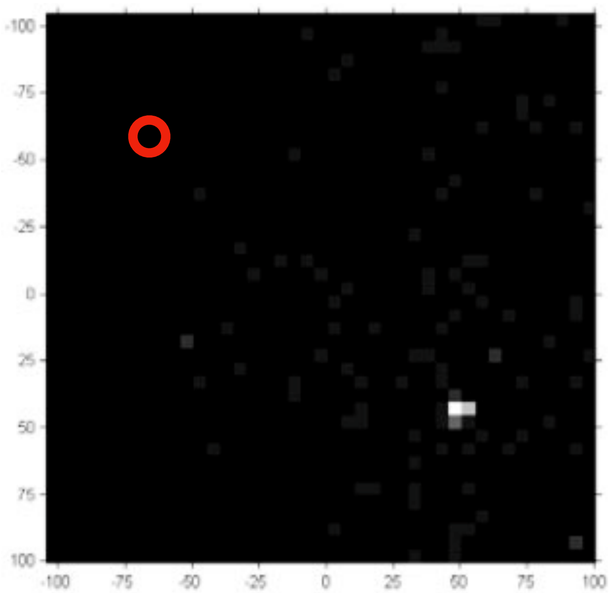

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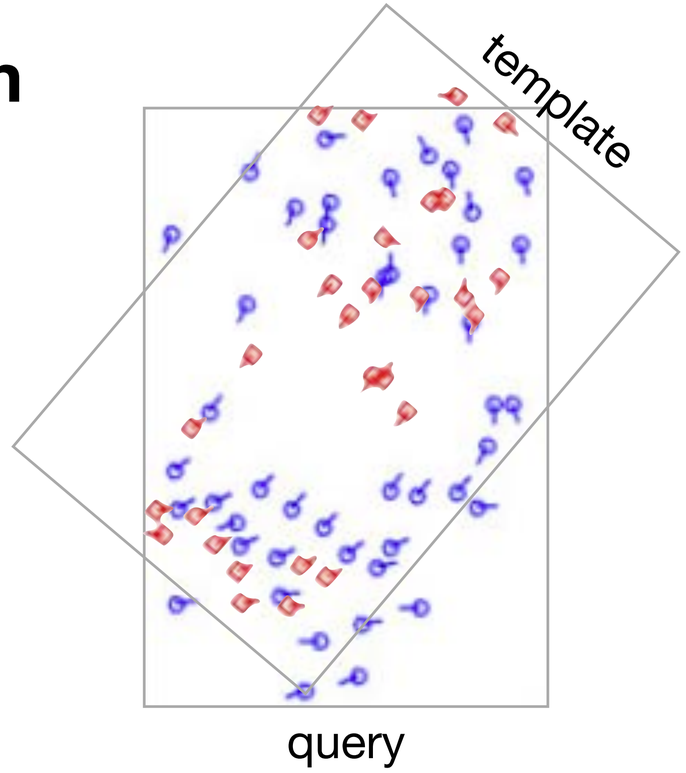
Feature Matching

Hough Transform



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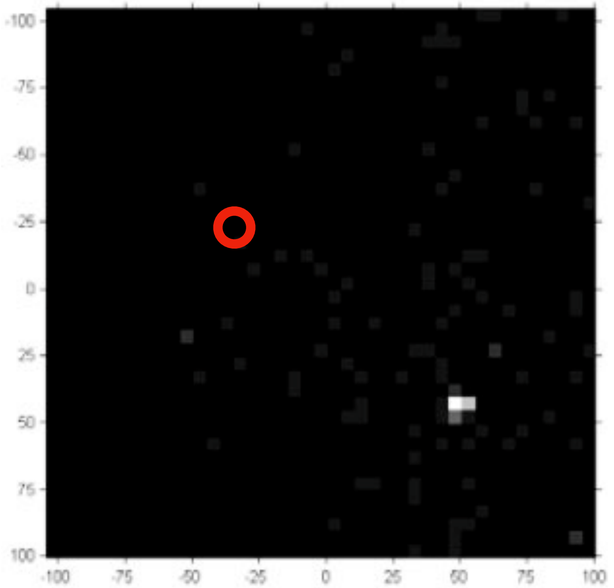

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Feature Matching

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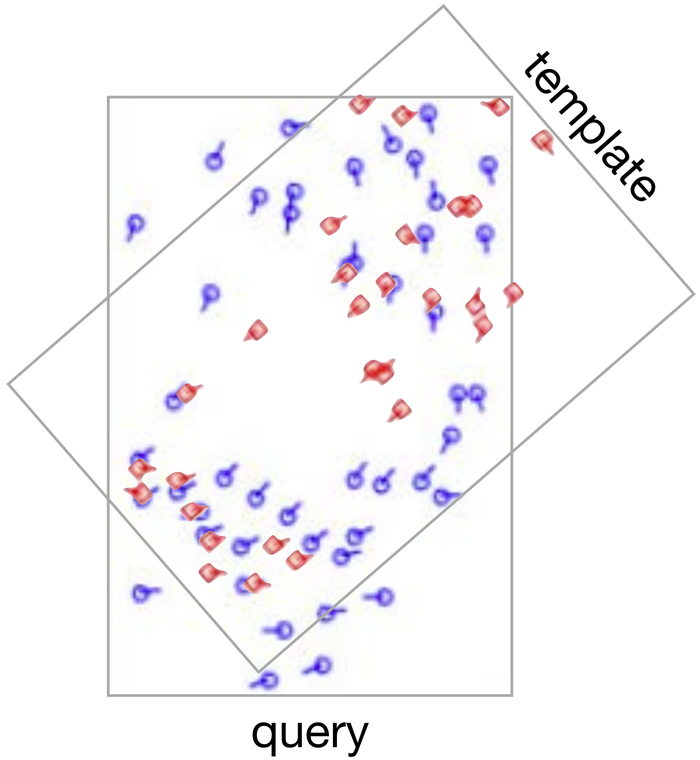

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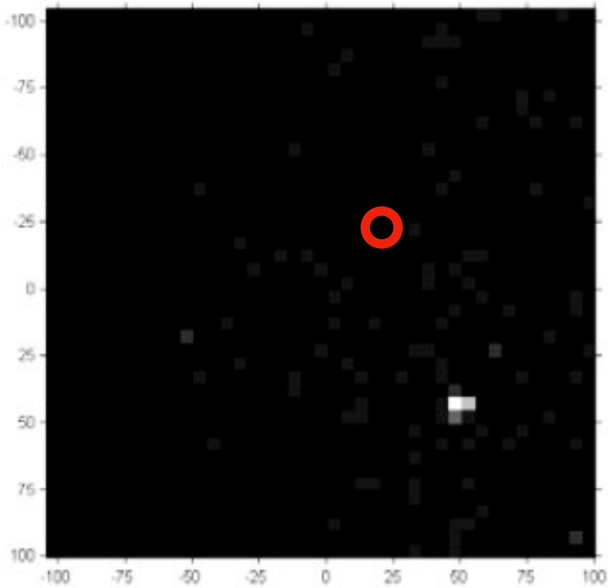
Springer Books, 2011



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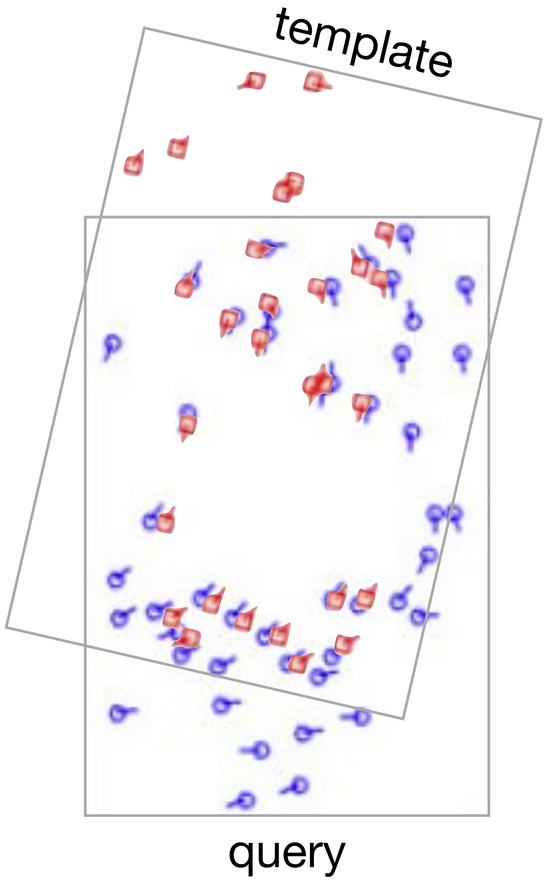
Feature Matching

Hough Transform



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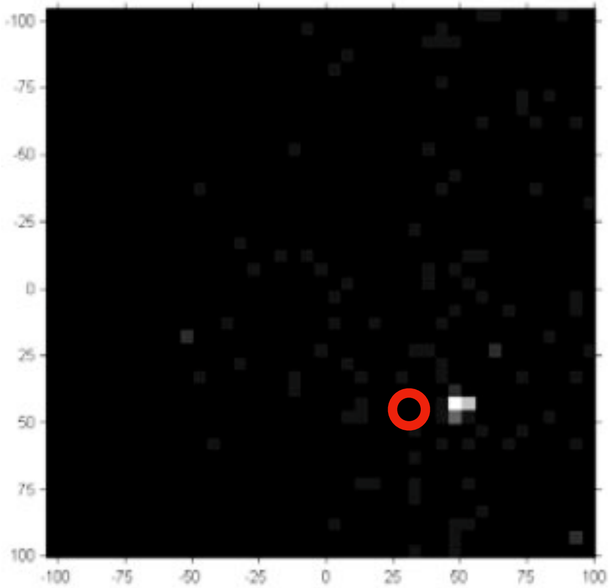

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LOYOLA UNIVERSITY CHICAGO

Feature Matching

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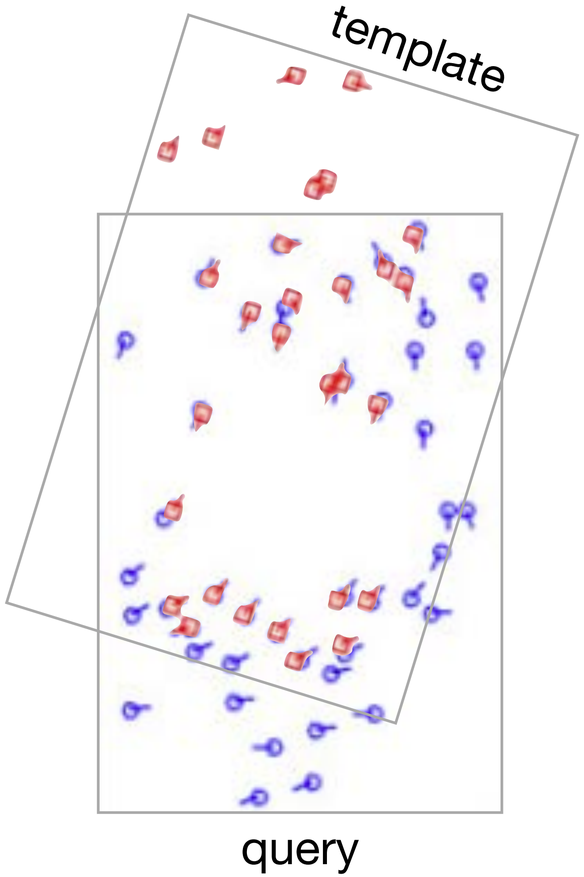

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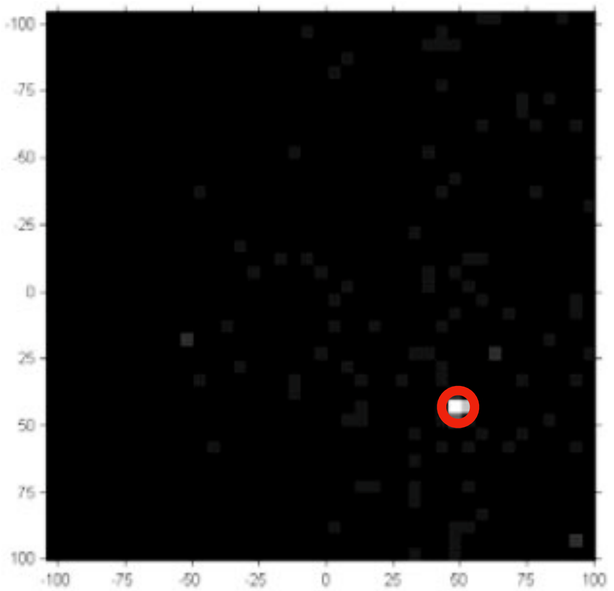
Springer Books, 2011



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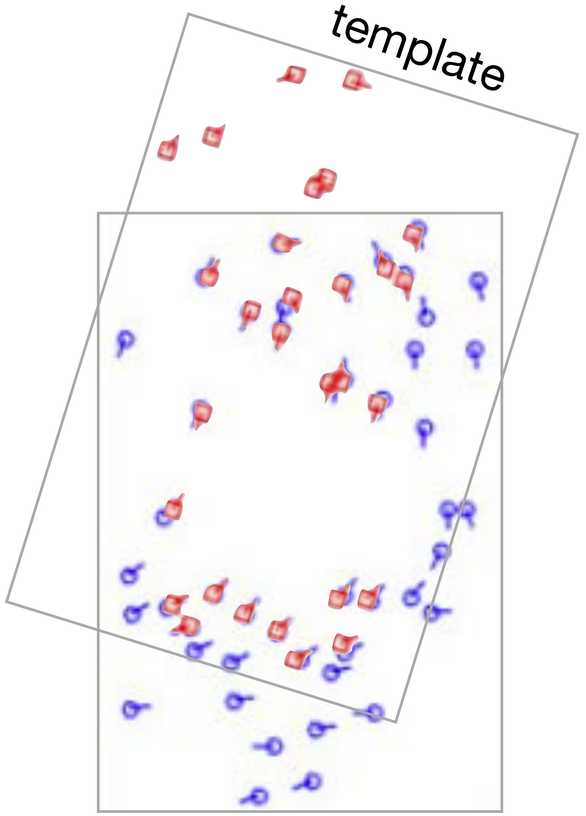
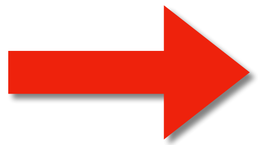
Feature Matching

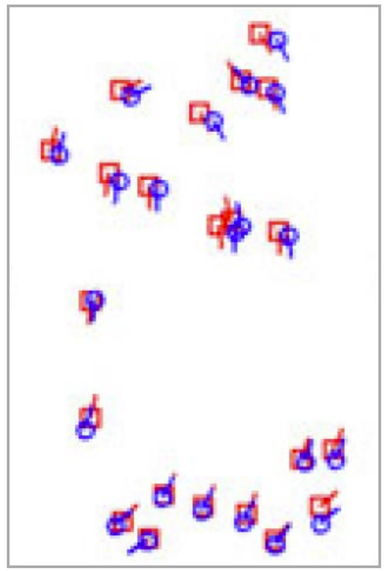
Hough Transform



query



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



21 matches

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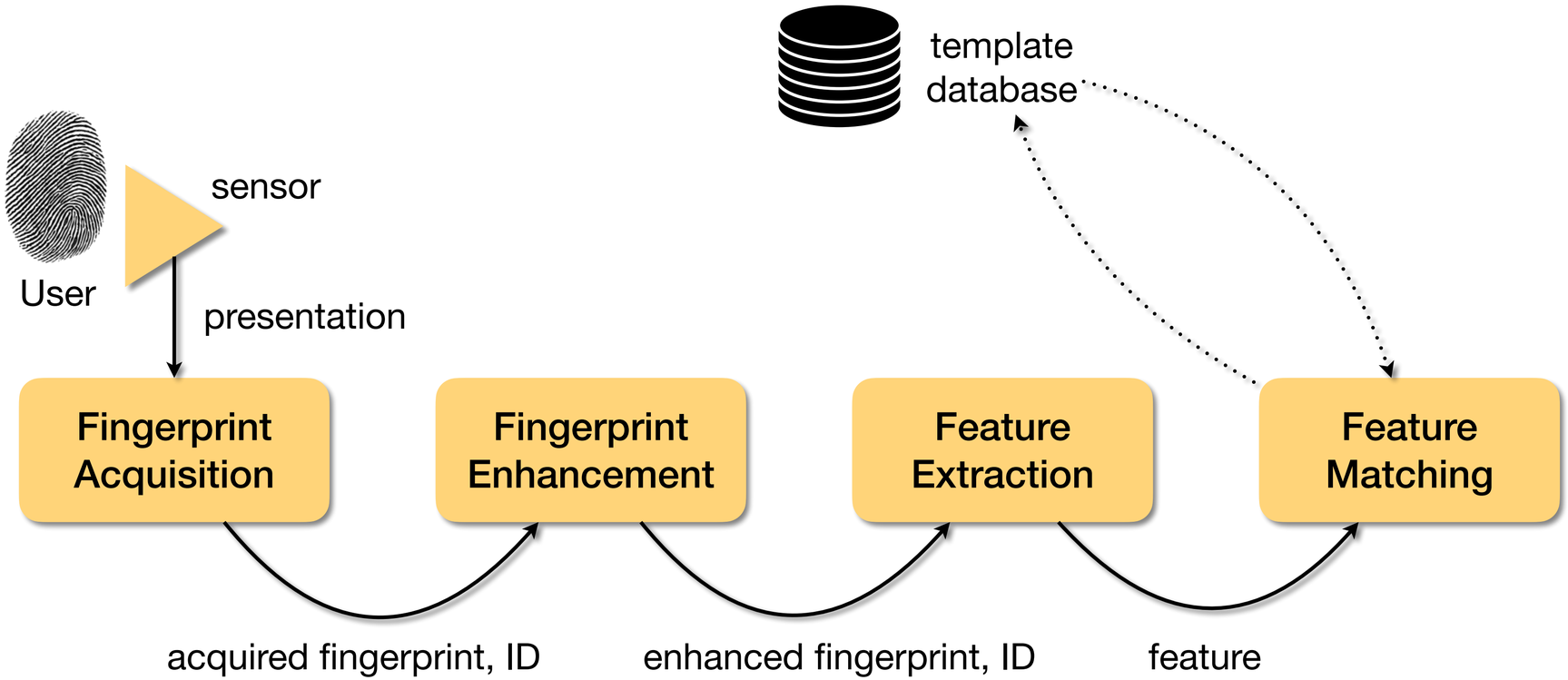
Fingerprint Recognition



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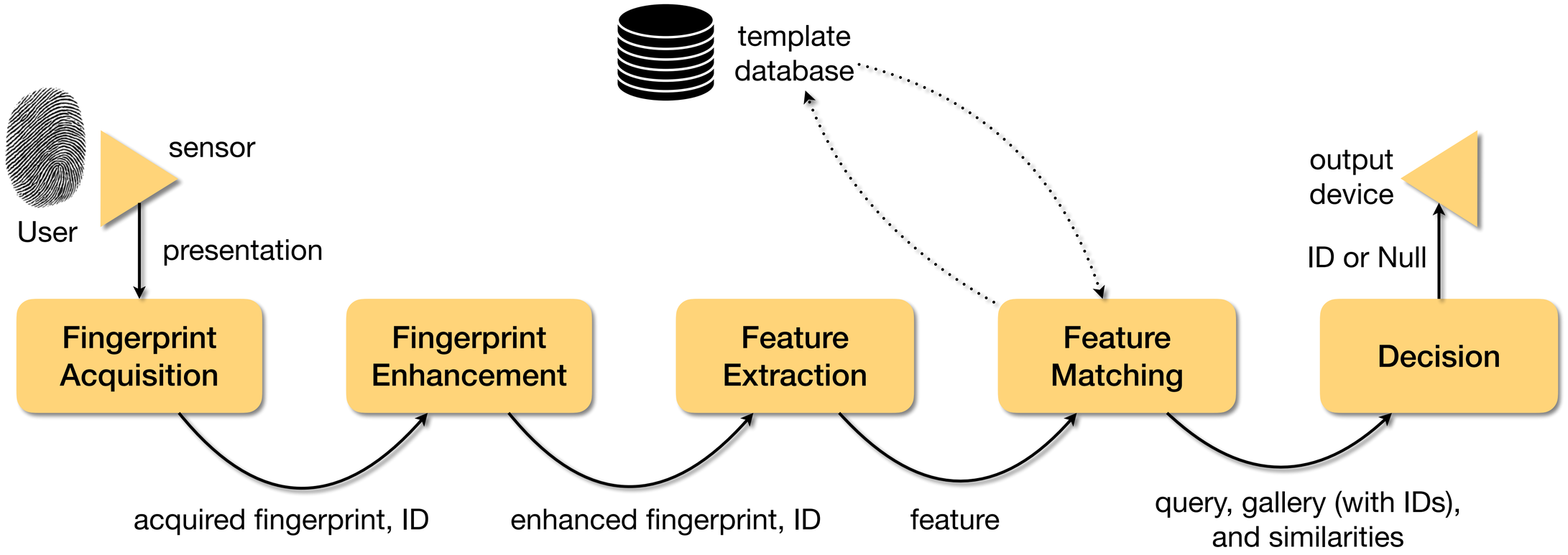
Fingerprint Recognition



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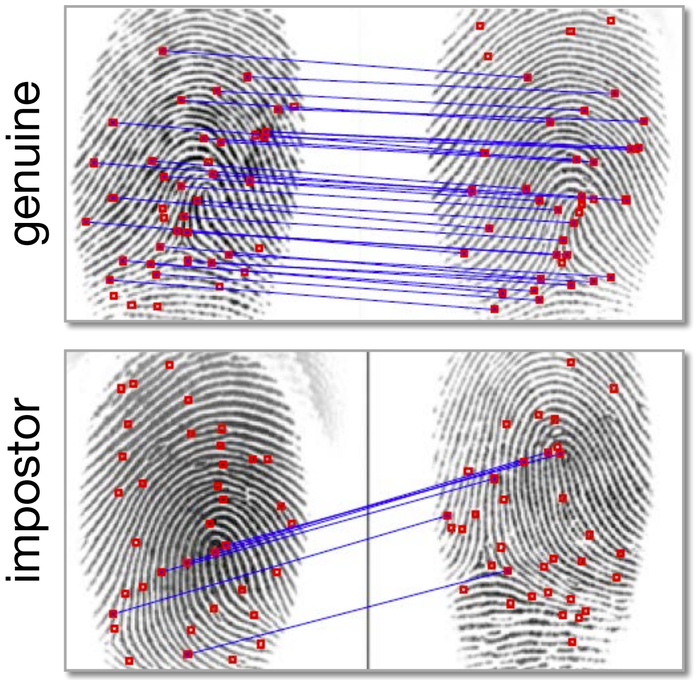
Decision

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

Similarity-based Decision

The number of minutiae matches express the **similarity** between two fingerprint samples.



Simple score

Let M be the number of minutiae in image i.

Let N be the number of minutiae in image j.

$$sim\_score = \frac{\#matches}{(M+N)/2}$$

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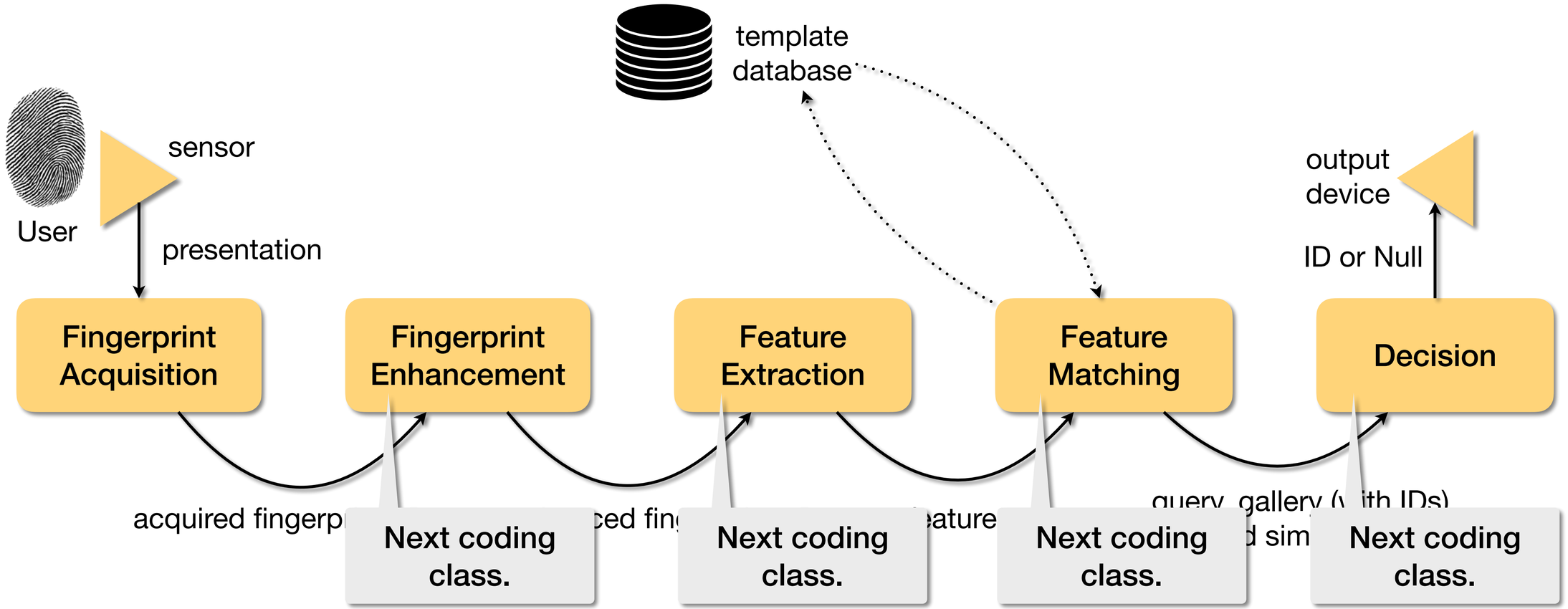
Fingerprint Recognition



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What's Next?

First data collection day
We'll collect and store our fingerprints.

Second coding class
We'll experiment with a fingerprint recognition implementation.

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

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