

Fingerprint Recognition III

COMP 388-002/488-002 Biometrics

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Fall 2026



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Today we will...

Get to know

Minutiae detection, description, and matching.

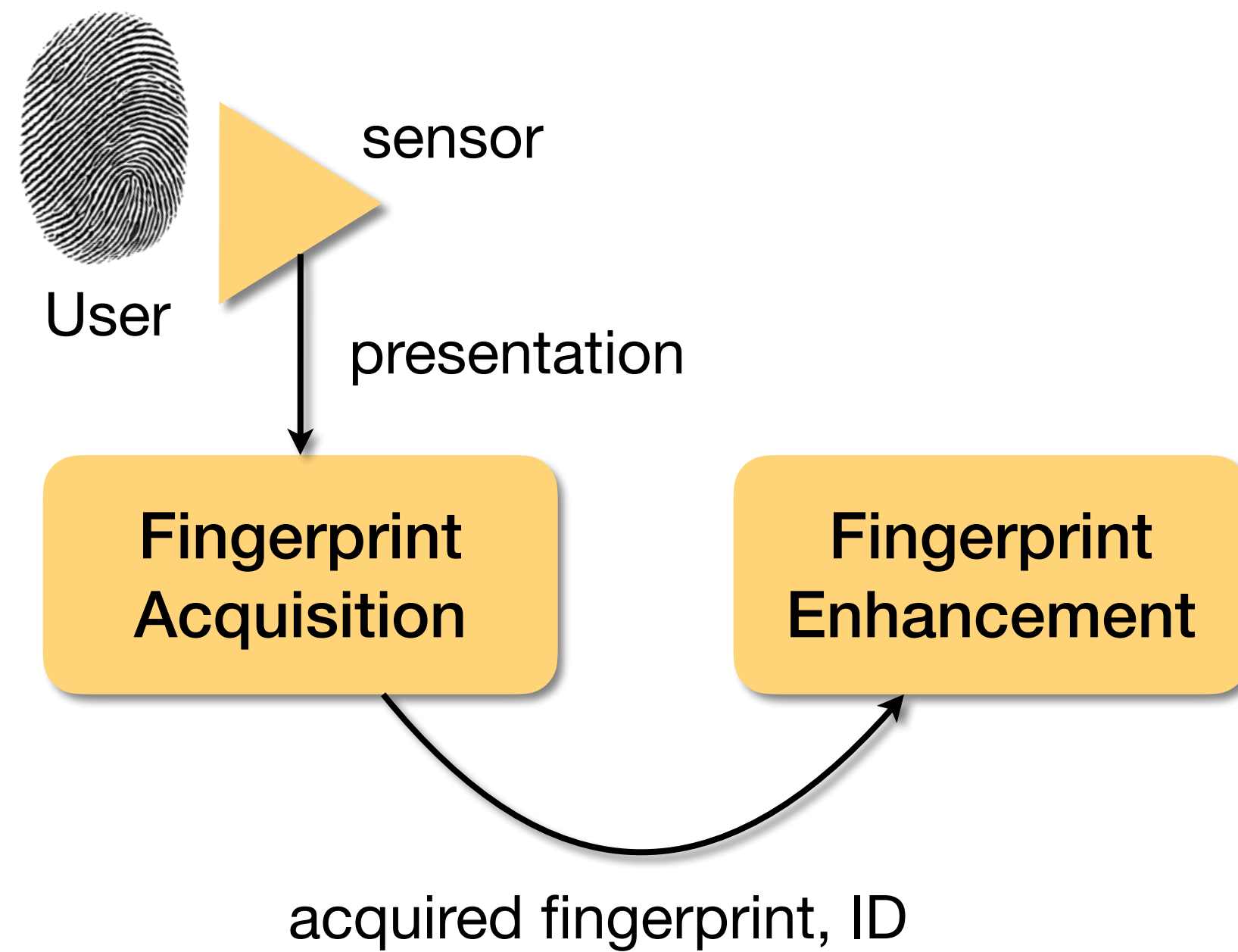
Today's Attendance

Please fill out the form

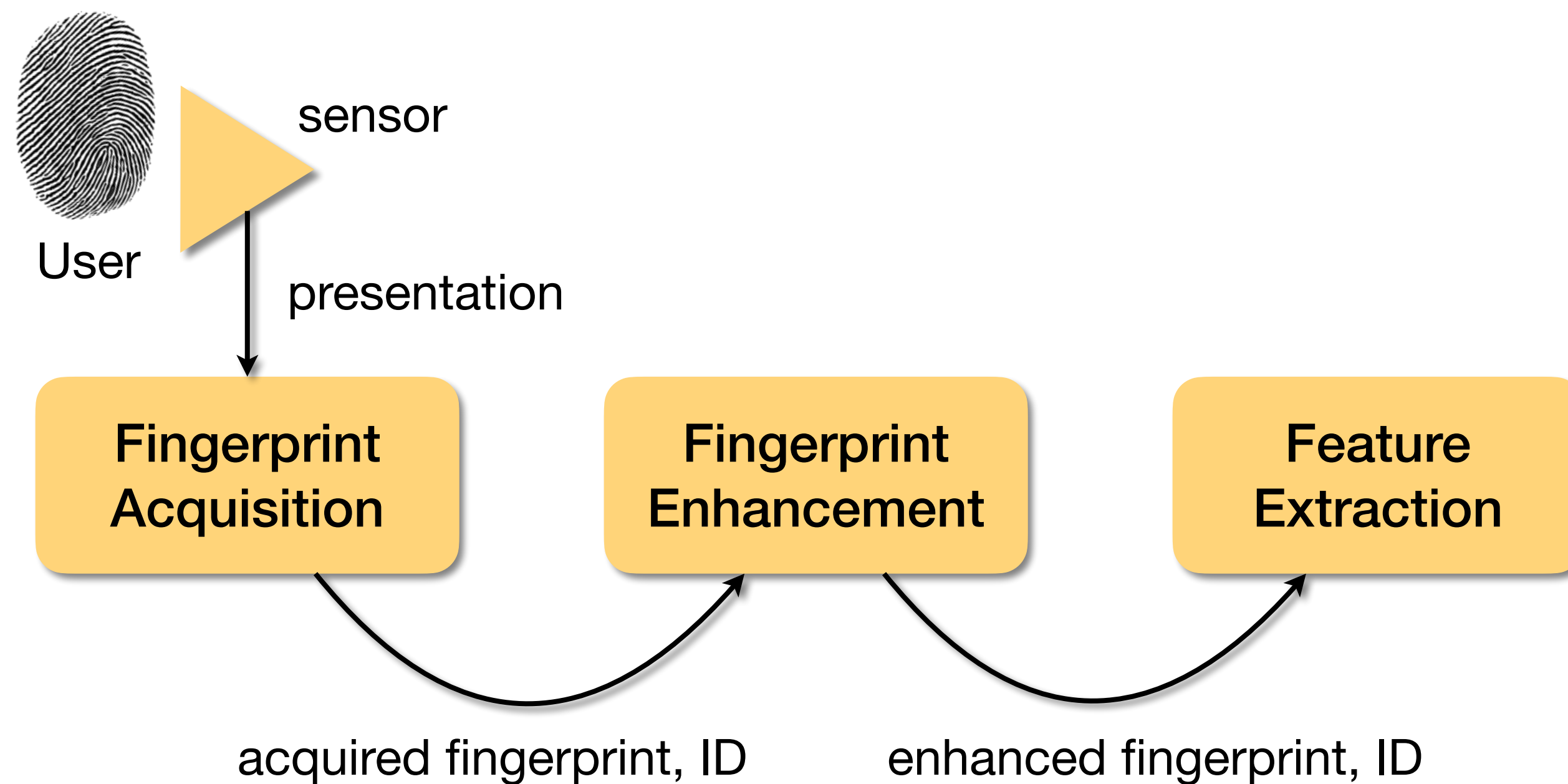
forms.gle/KGktbgdVuq4tuxRRA



Fingerprint Recognition



Fingerprint Recognition



Feature Extraction

Three Levels of Features

From coarse to fine:

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



Feature Extraction

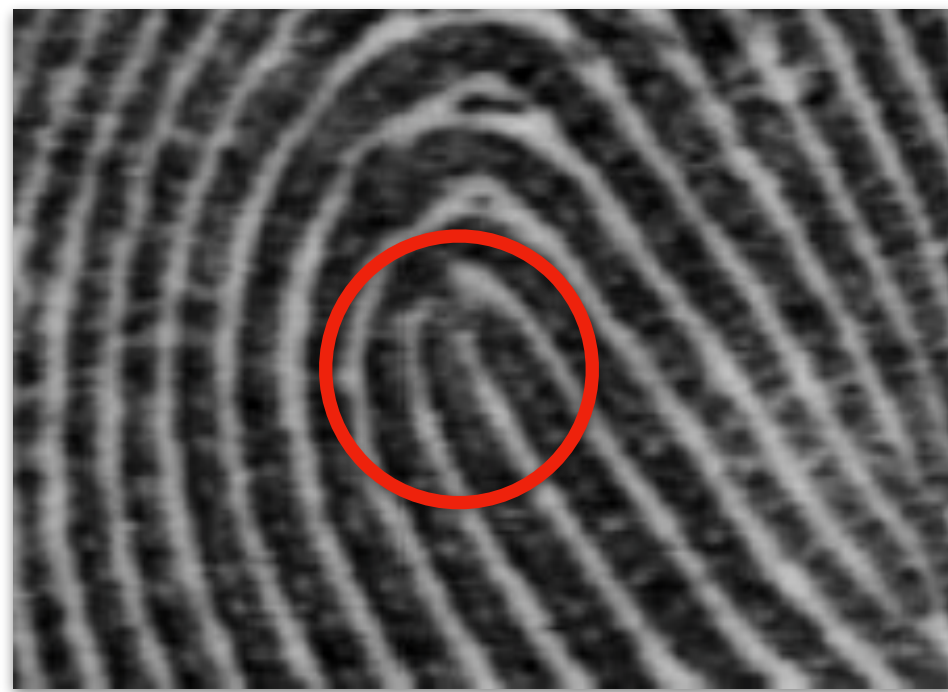
Level-1 Features

Singular points and core.

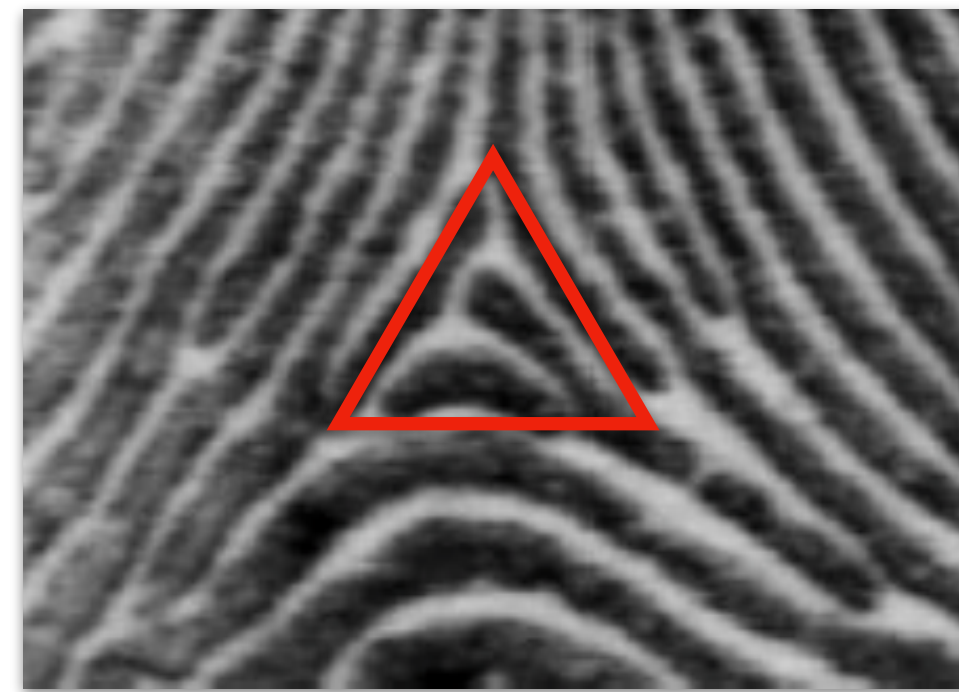
Recommended capture resolution: 250 ppi (pixels per inch).

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

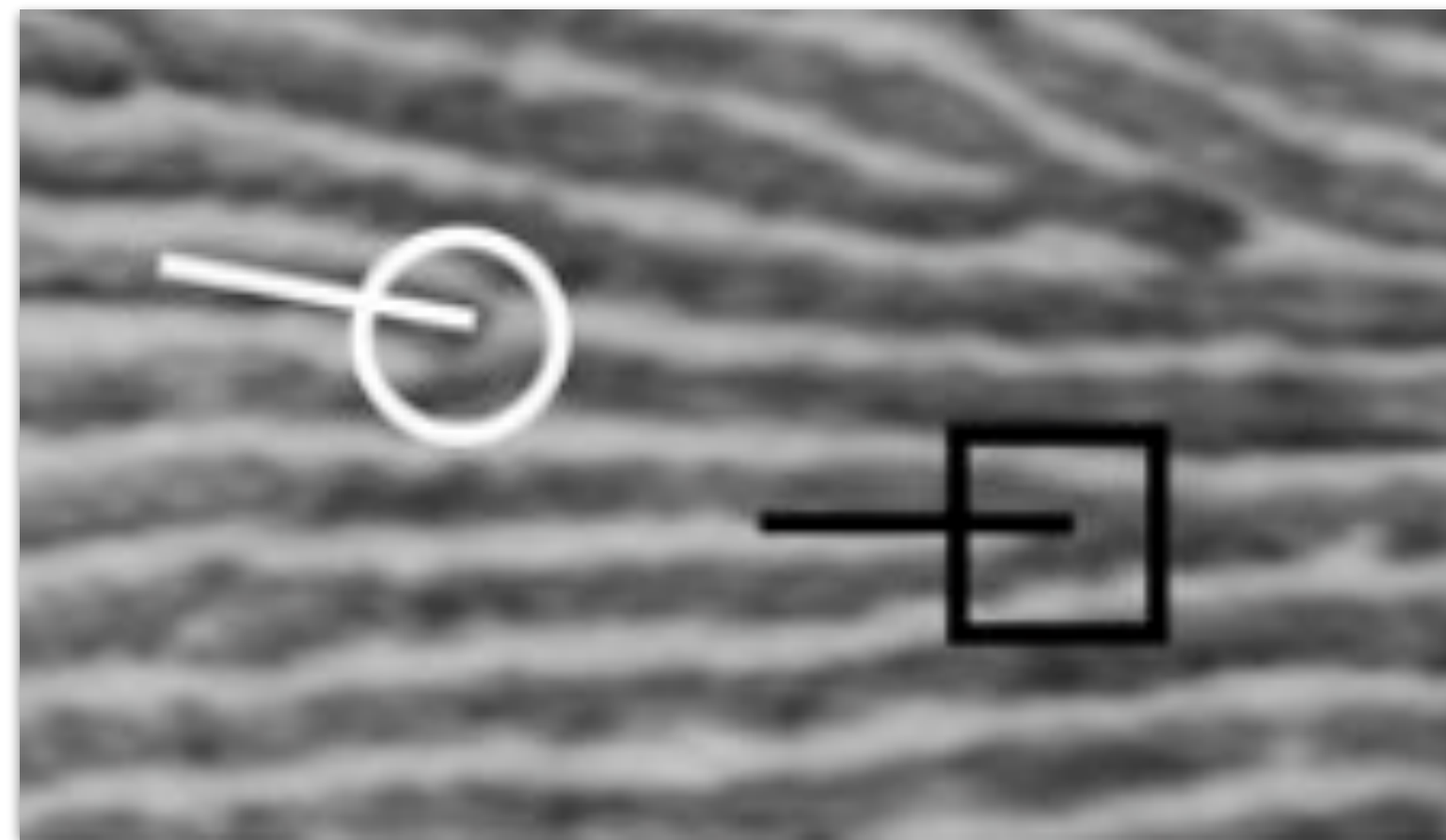
Level-2 Features

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

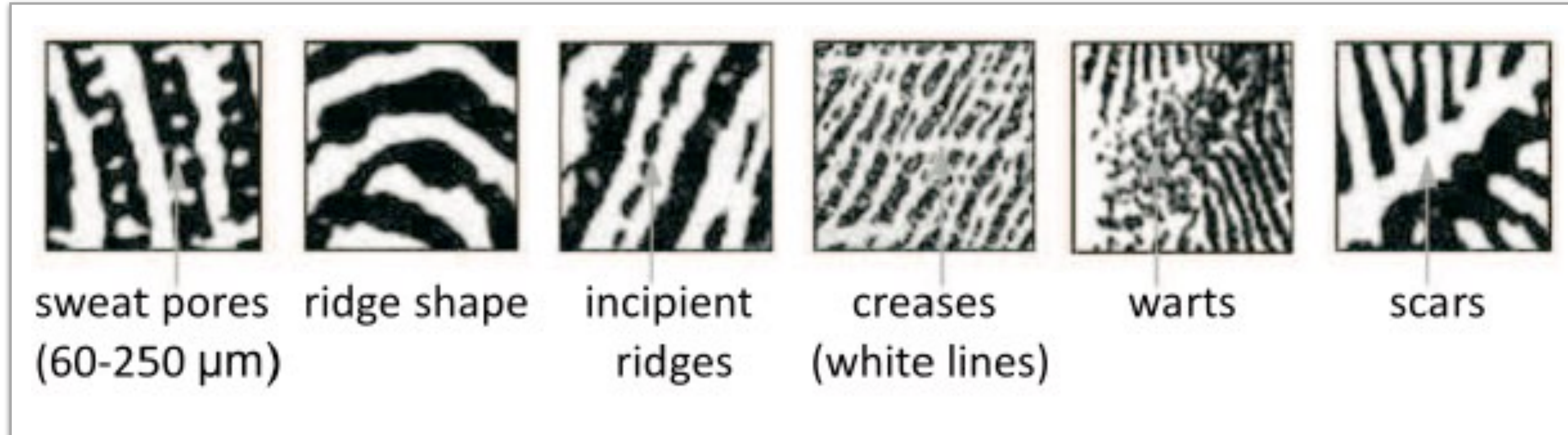
Features

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

Feature Extraction

Three Levels of Features

From coarse to fine:

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



Let's dive into it...

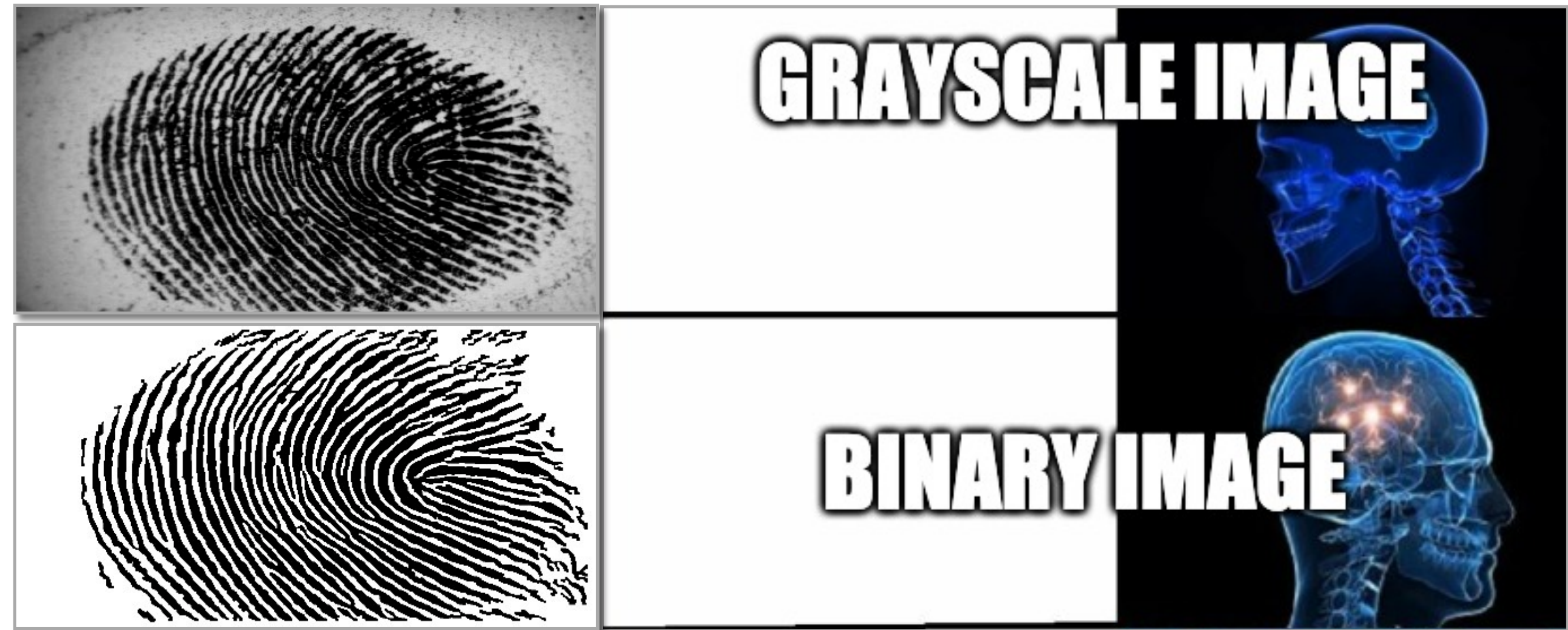
Minutiae Detection

Three Stages
Start from...



Minutiae Detection

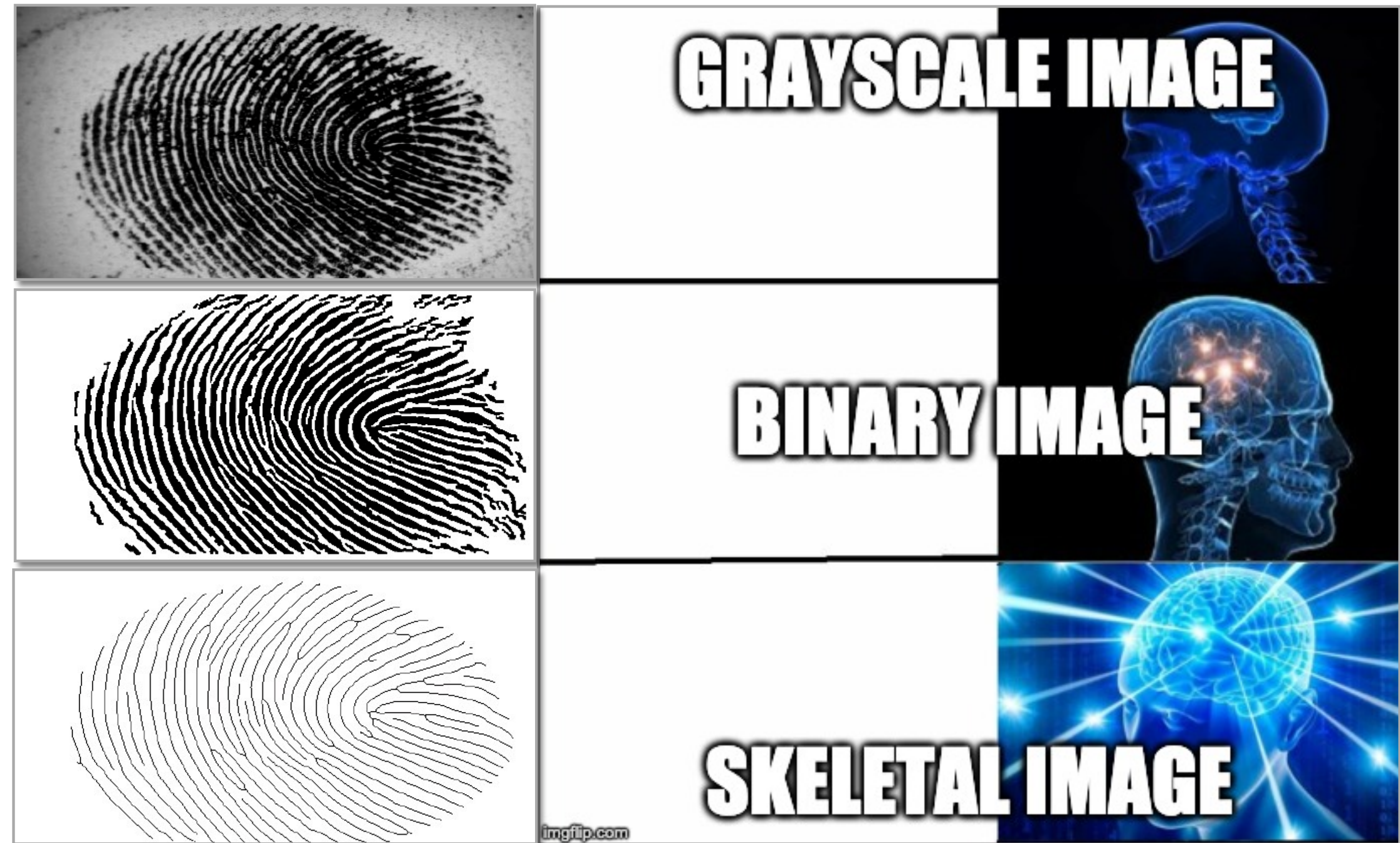
Three Stages
Start from...



Minutiae Detection

Three Stages

Start from...



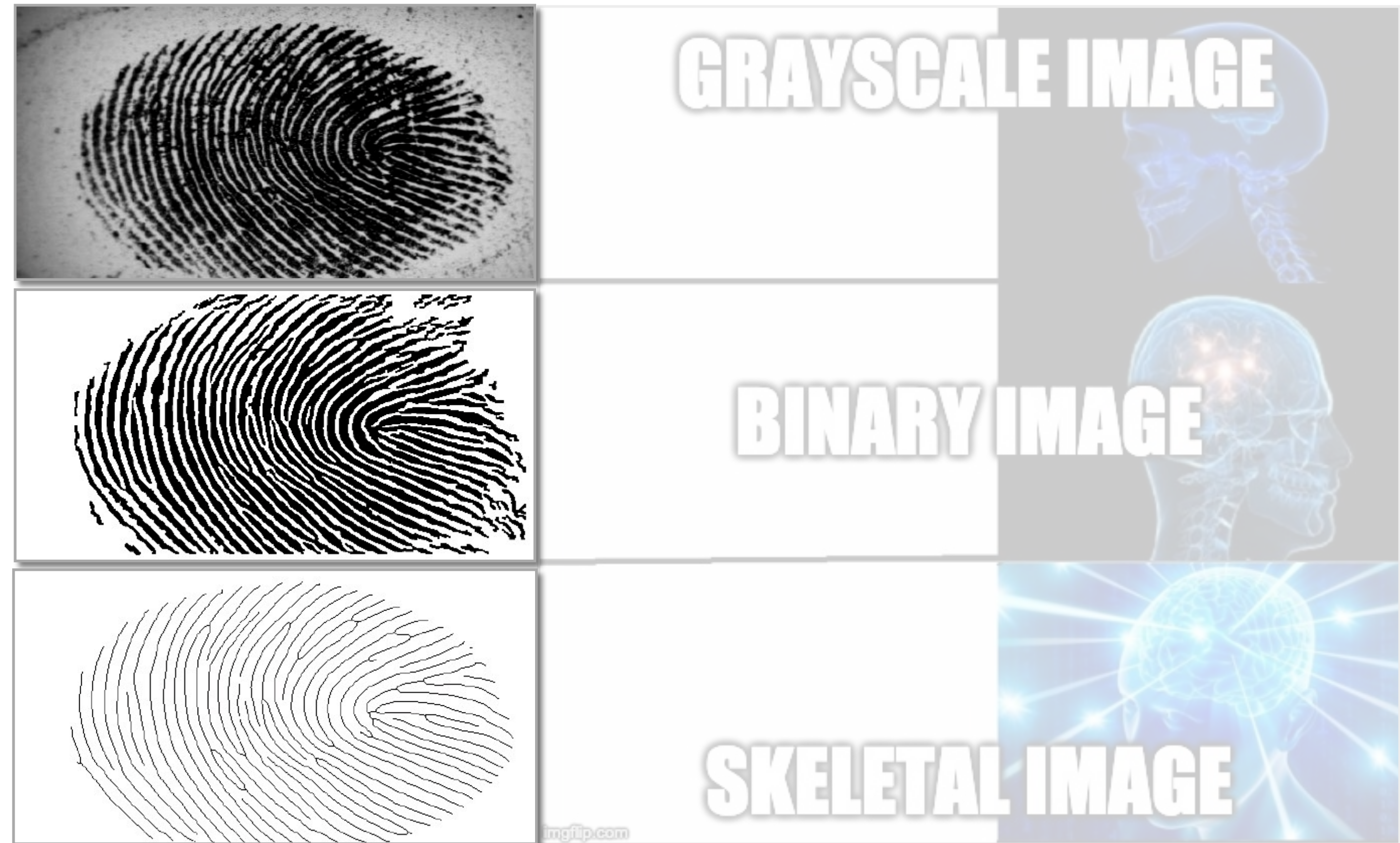
Source: Dr. Adam Czajka

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

Minutiae Detection

Source: Dr. Adam Czajka

Grayscale Images

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

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.



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

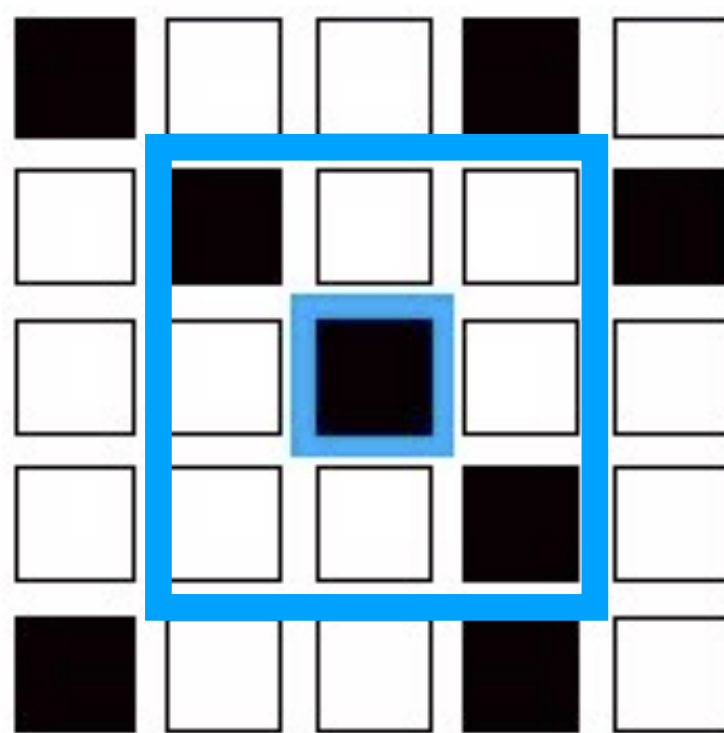


Let's dive into it...

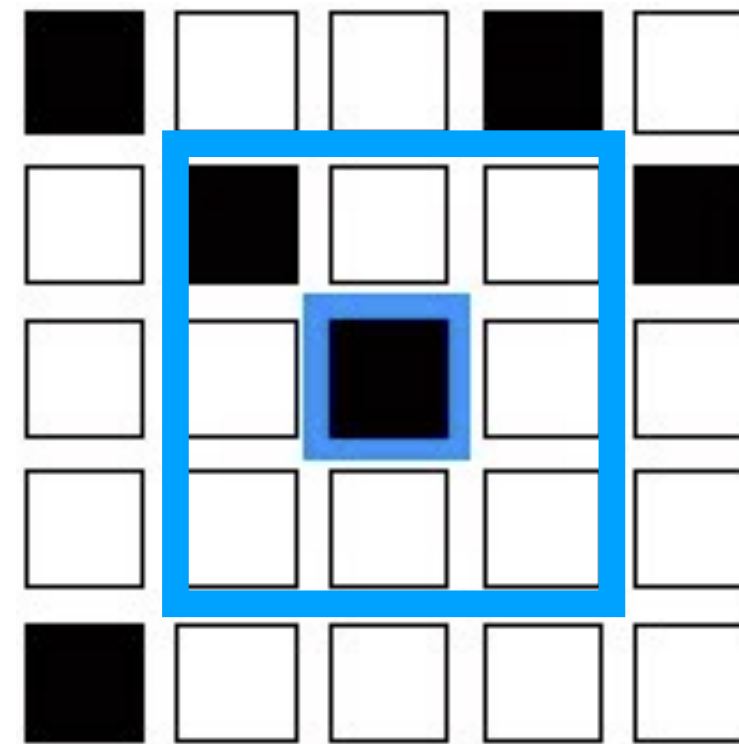
Minutiae Detection

Skeletal Images

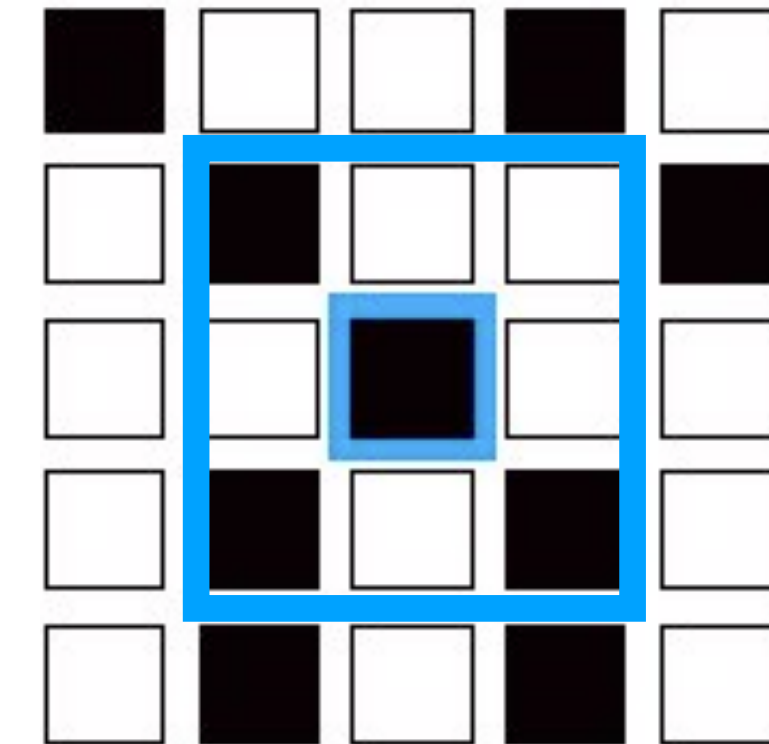
Analyze each ridge pixel neighborhood.
Count the number of ridge pixels ($\#RP$).



$\#RP = 3$
No minutiae



$\#RP < 3$
Ridge end



$\#RP > 3$
Ridge bifurcation

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

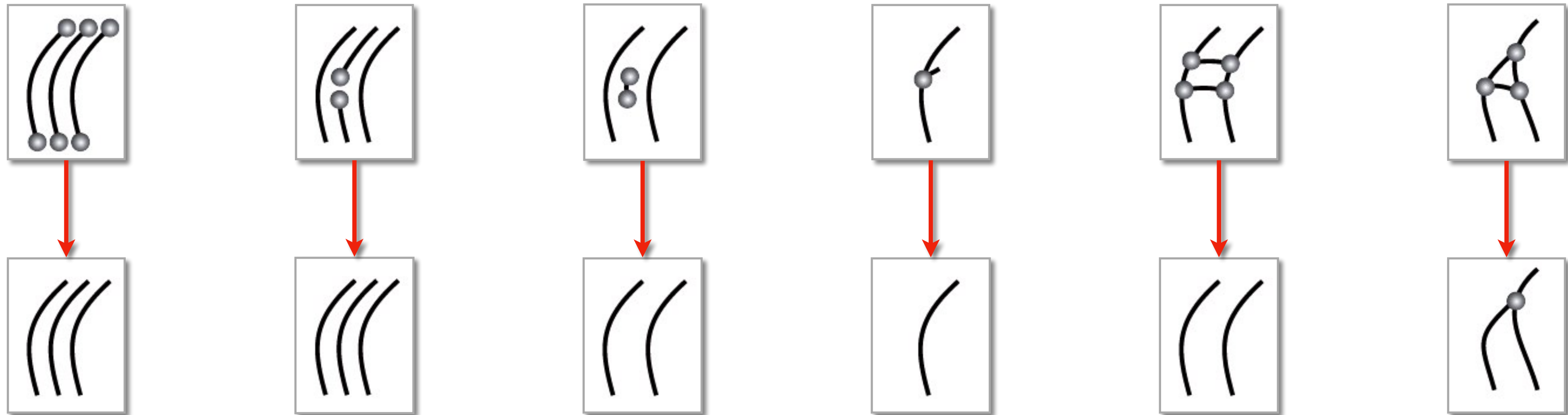
Minutiae Detection

Skeletal Images

Remove false positive minutiae.

Example Heuristics:

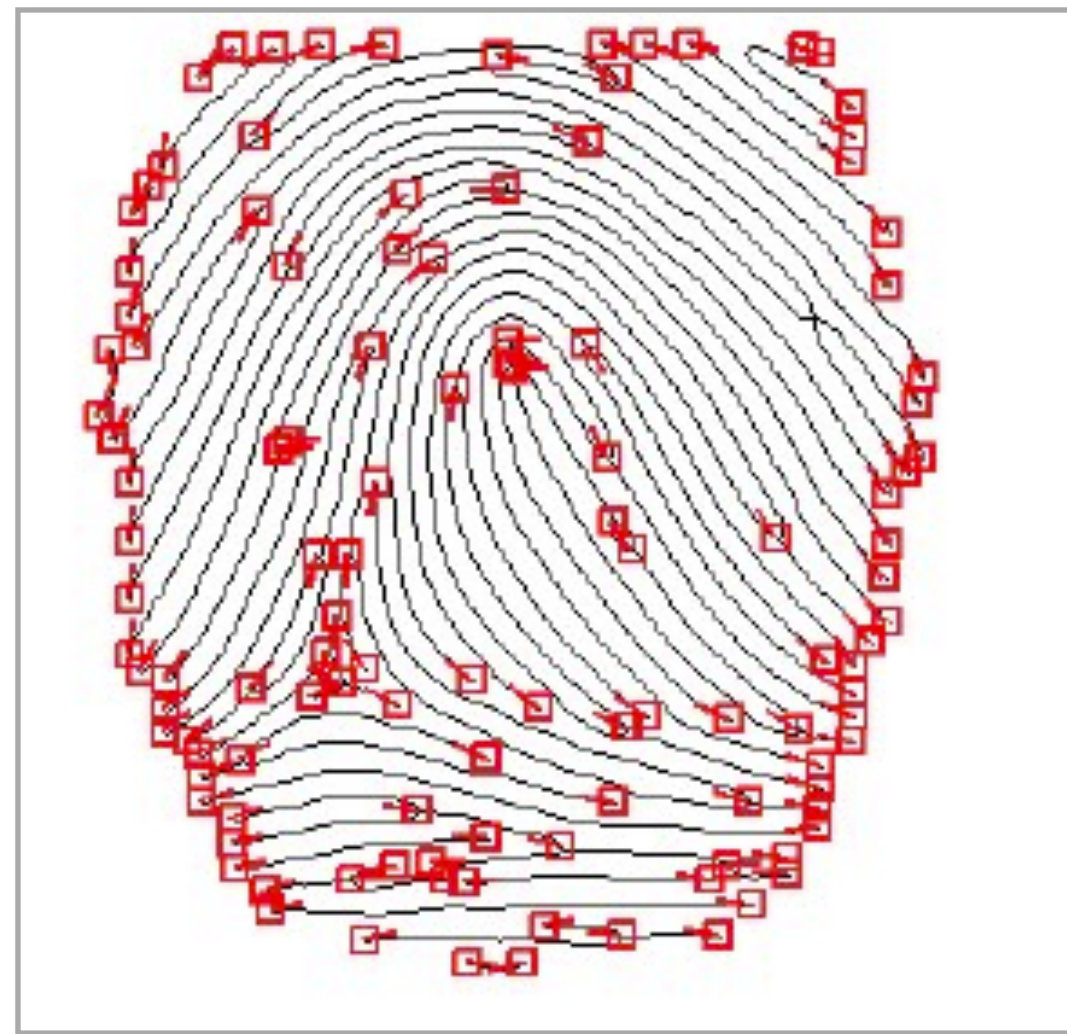
Source: Dr. Adam Czajka



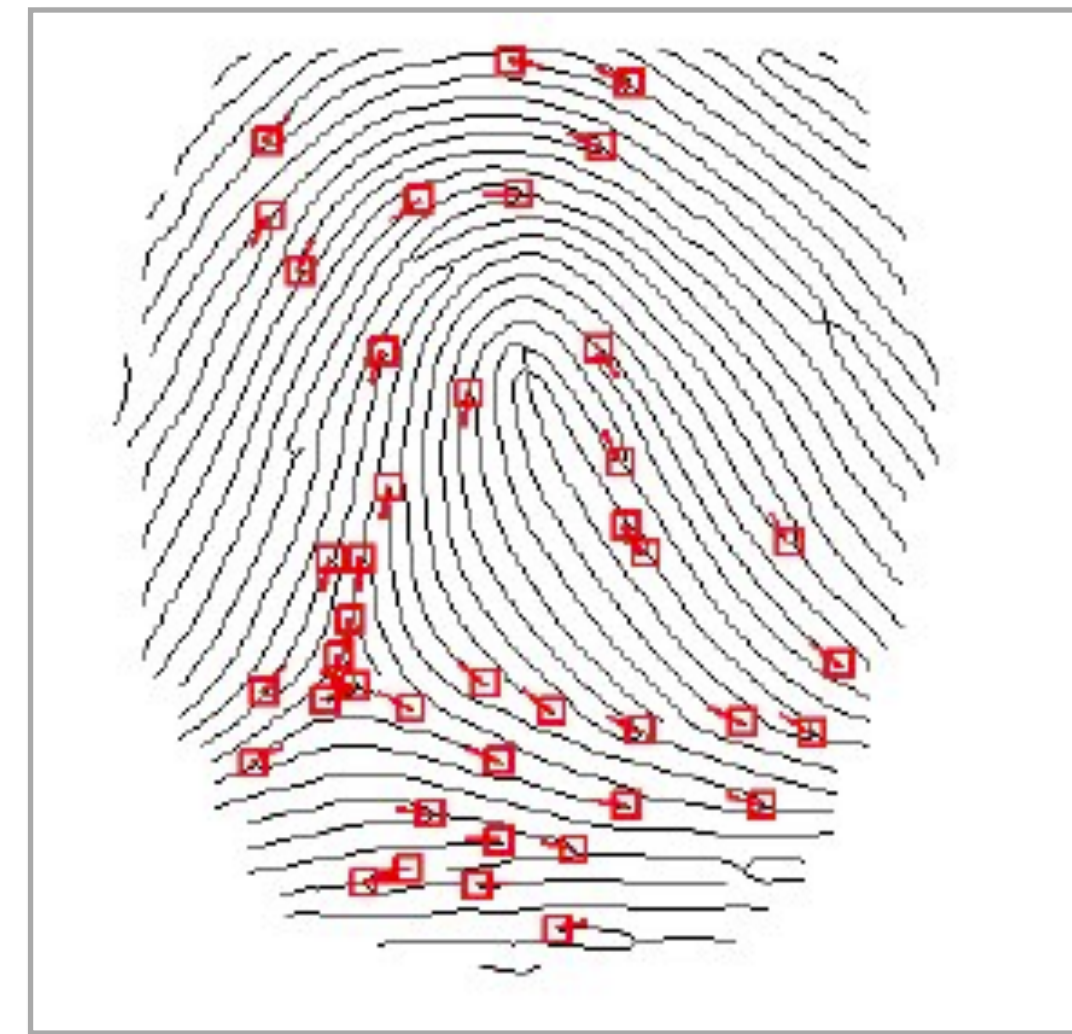
Minutiae Detection

Skeletal Images

Remove false positive minutiae.



before



after

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

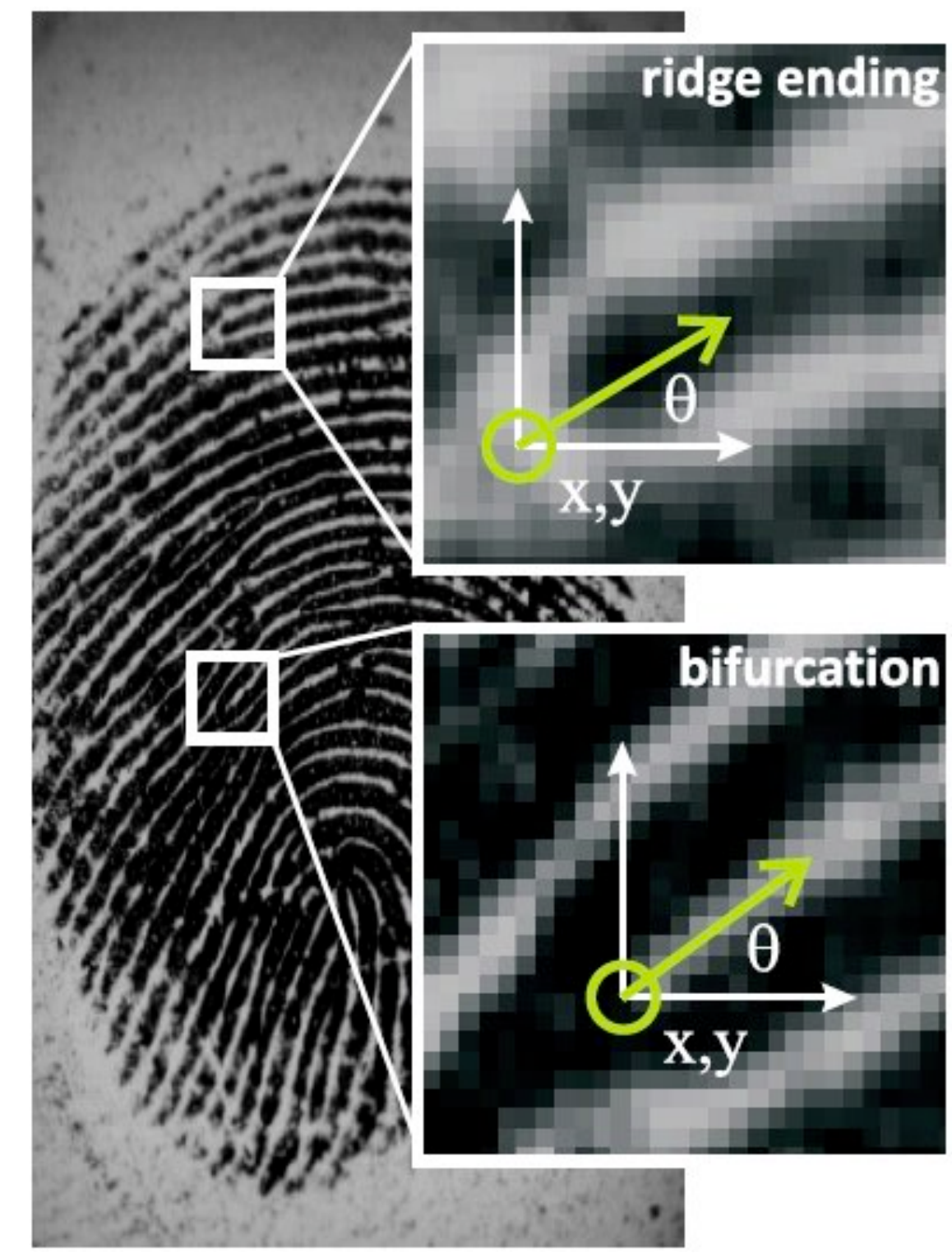
Minutiae Description

ISO/IEC FDIS 19794-2 (2011)

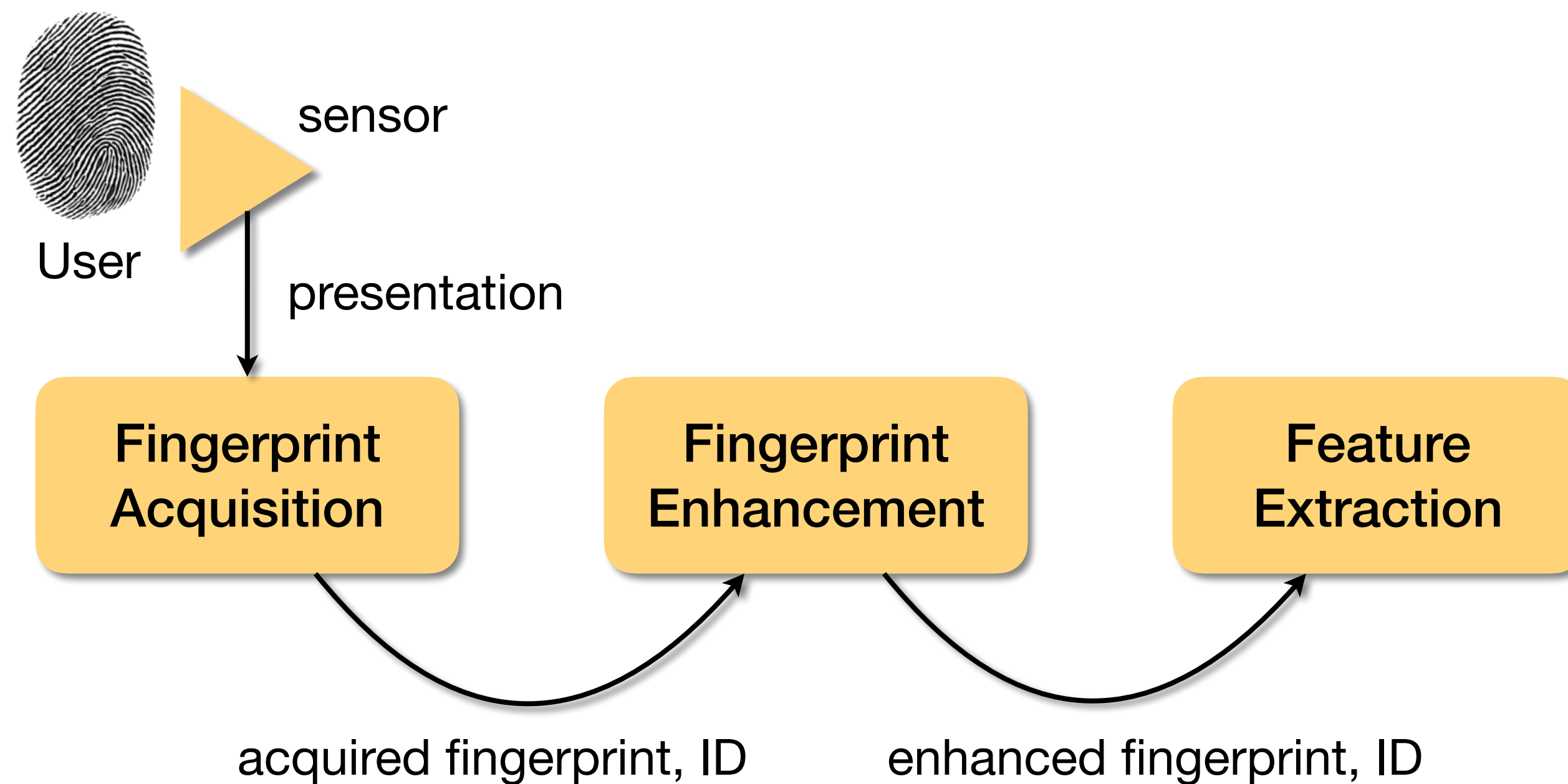
For each minutiae,
store position (x, y) and
angle θ .

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

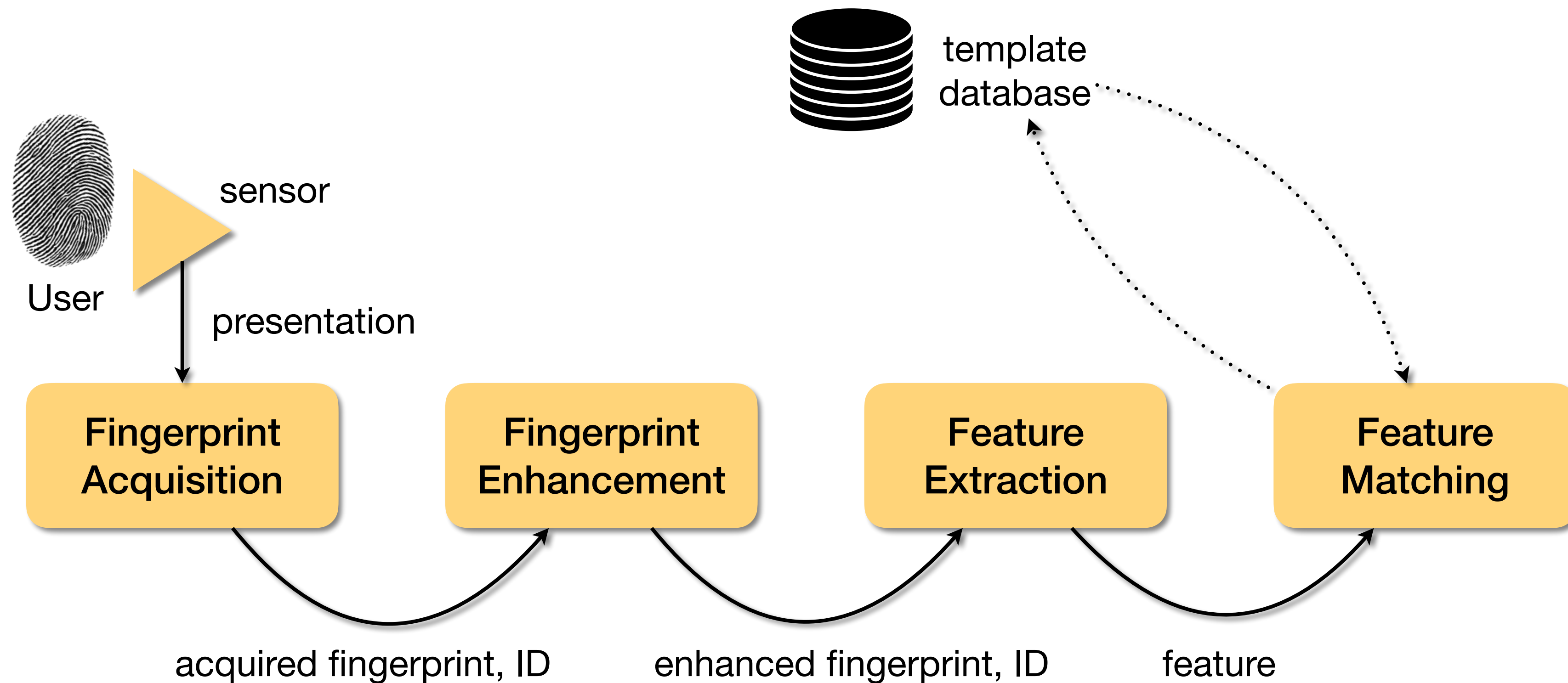
Source: Dr. Adam Czajka



Fingerprint Recognition



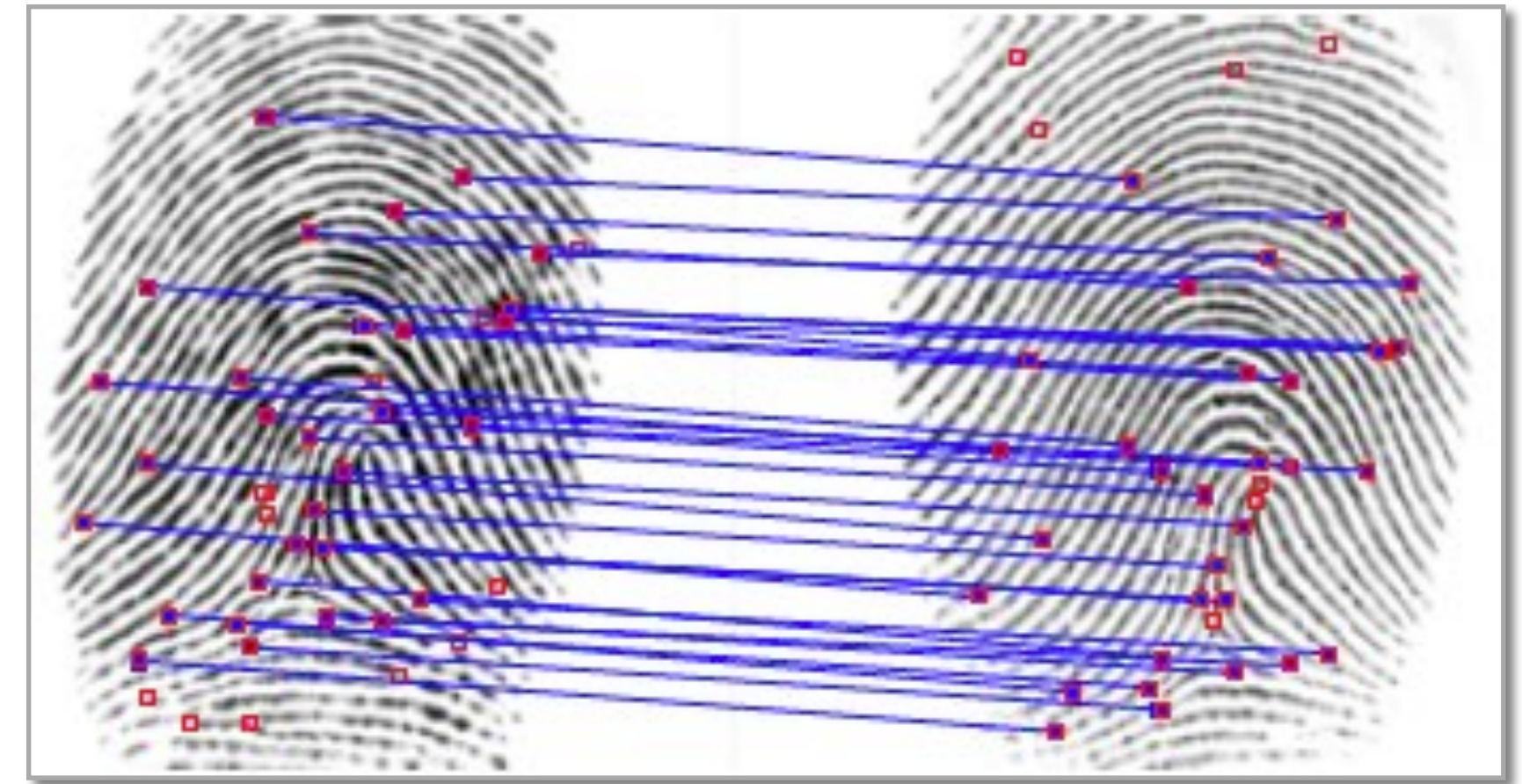
Fingerprint Recognition



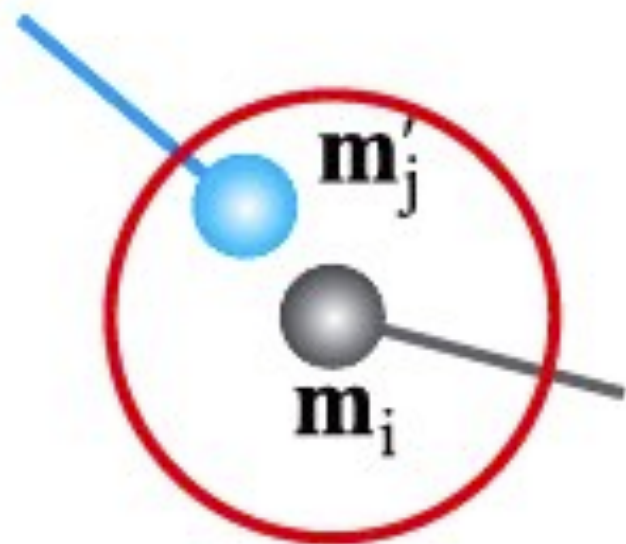
Feature Matching

How to establish pairs of corresponding minutiae between two samples?

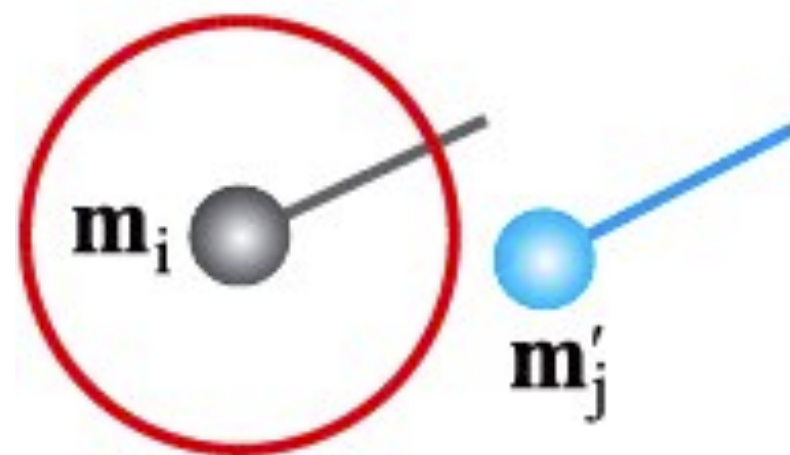
Check for agreements between both (x, y) **positions** and θ **angles**.



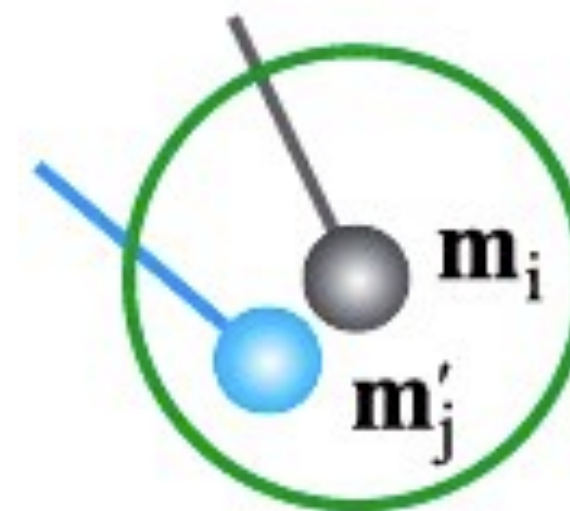
Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011



X Positions agree,
but angles do not.



X Angles agree, but
positions do not.



✓ 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

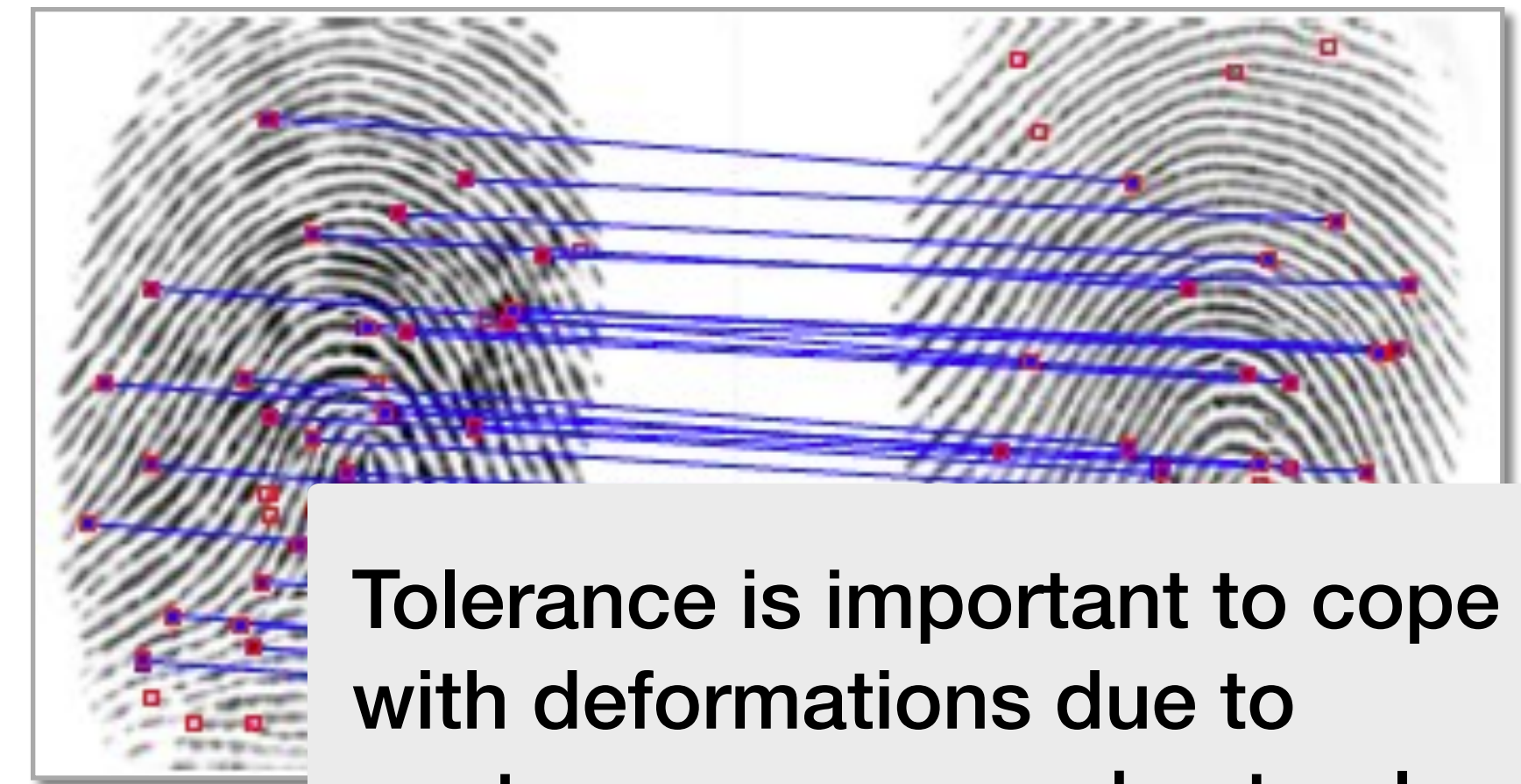


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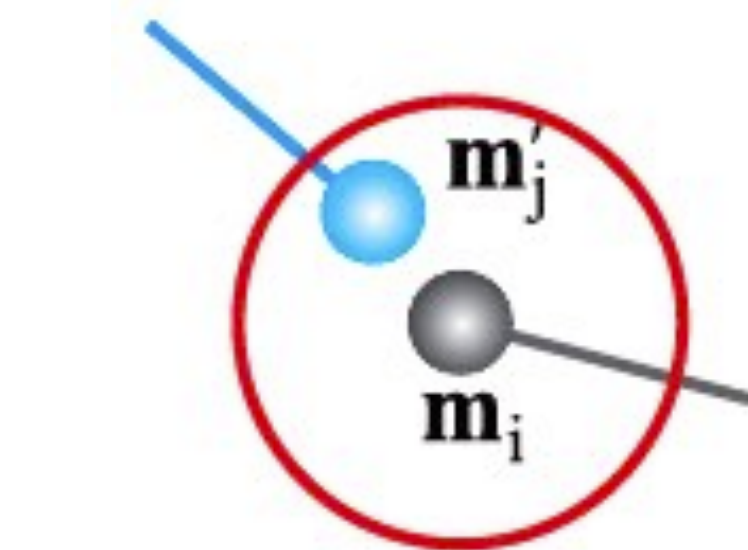
Feature Matching

How to establish pairs of corresponding minutiae between two samples?

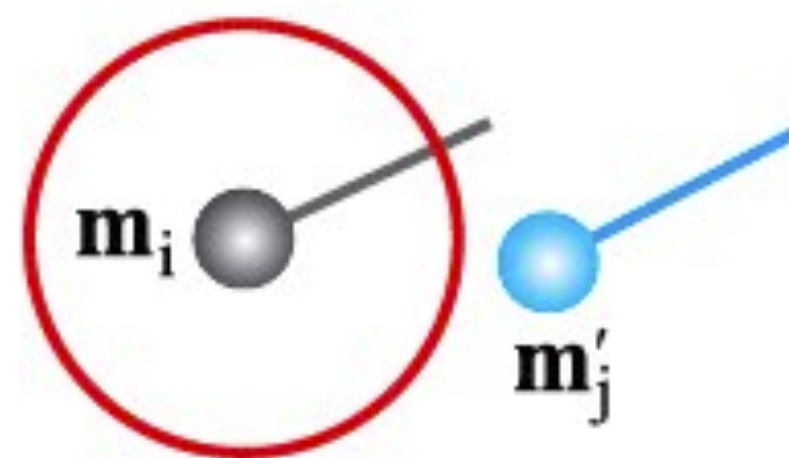
Check for agreements between both (x, y) **positions** and θ **angles**.



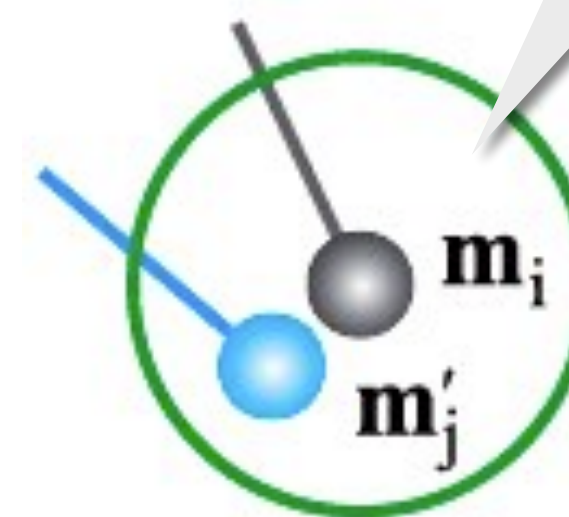
Tolerance is important to cope with deformations due to capture process and natural skin deformations.



✗ Positions agree, but angles do not.



✗ Angles agree, but positions do not.



✓ 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



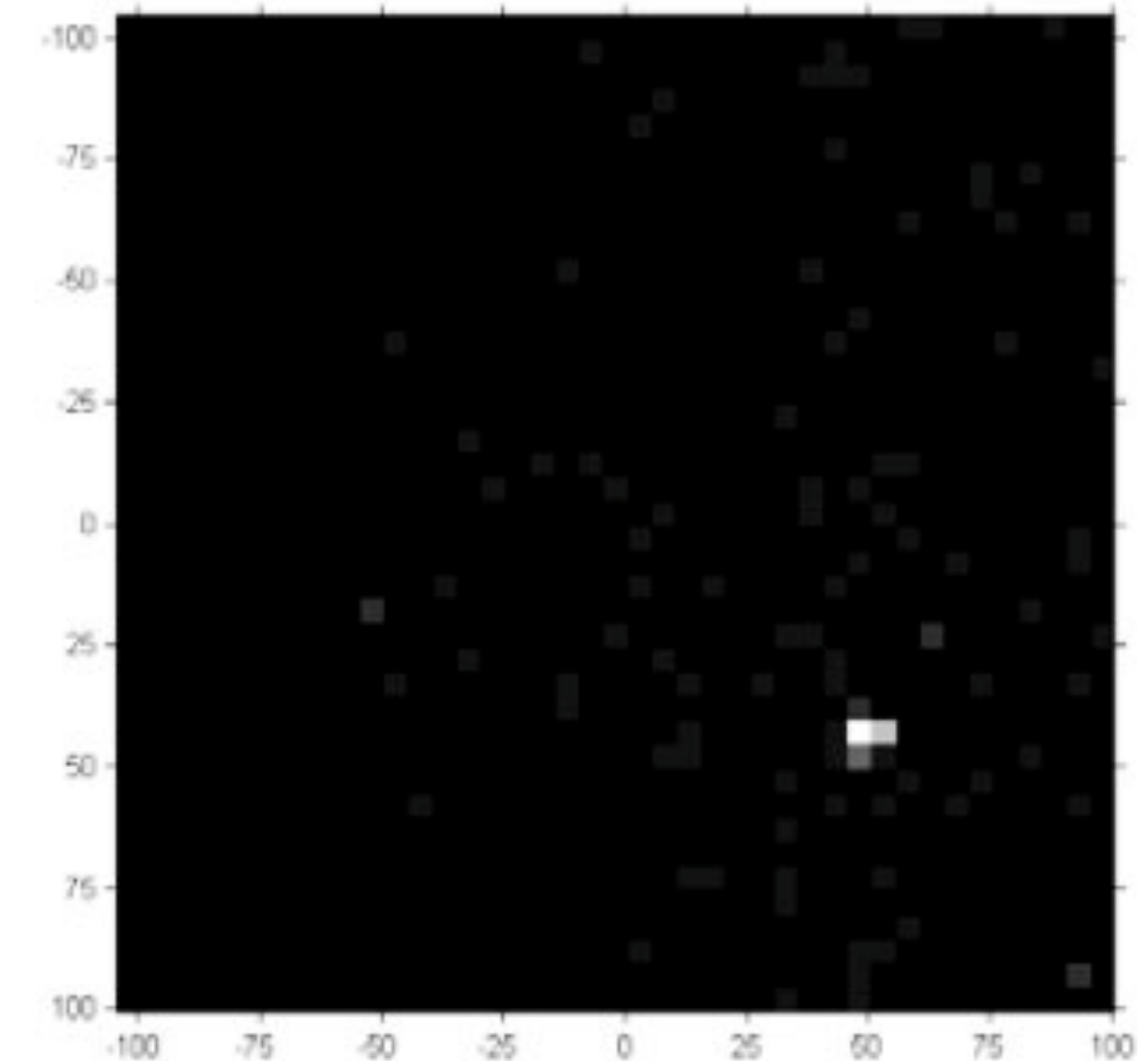
template

Feature Matching

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

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.



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

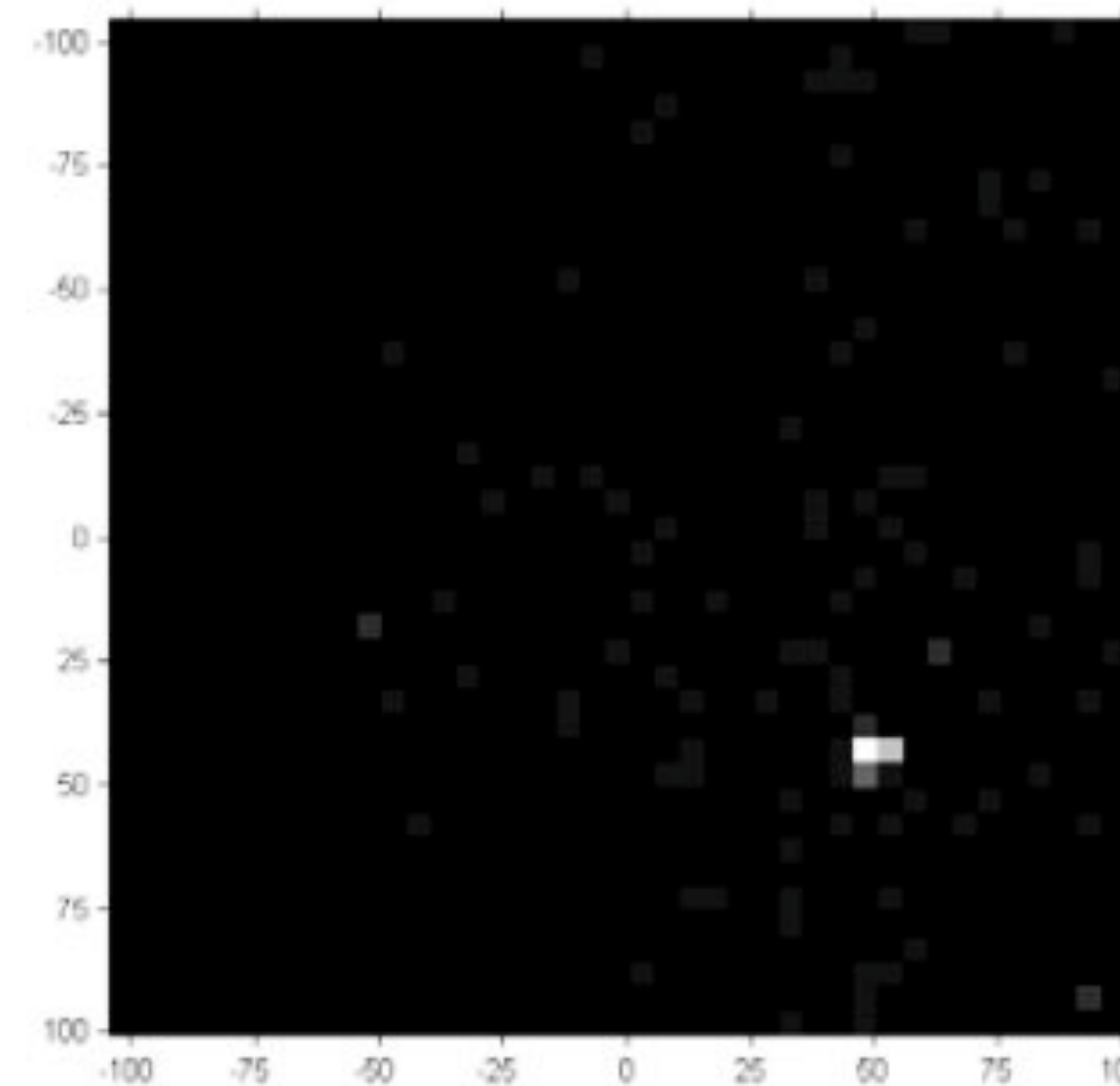
Feature Matching

Hough Transform



query

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

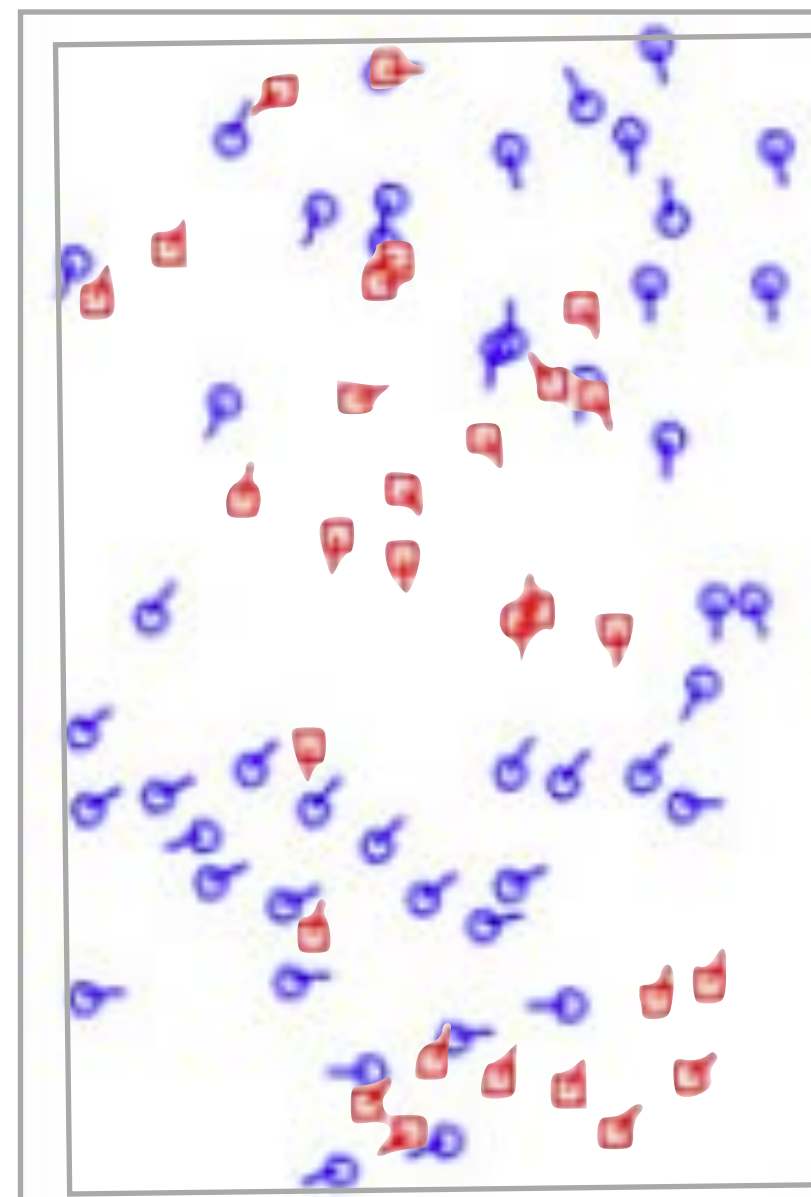


Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

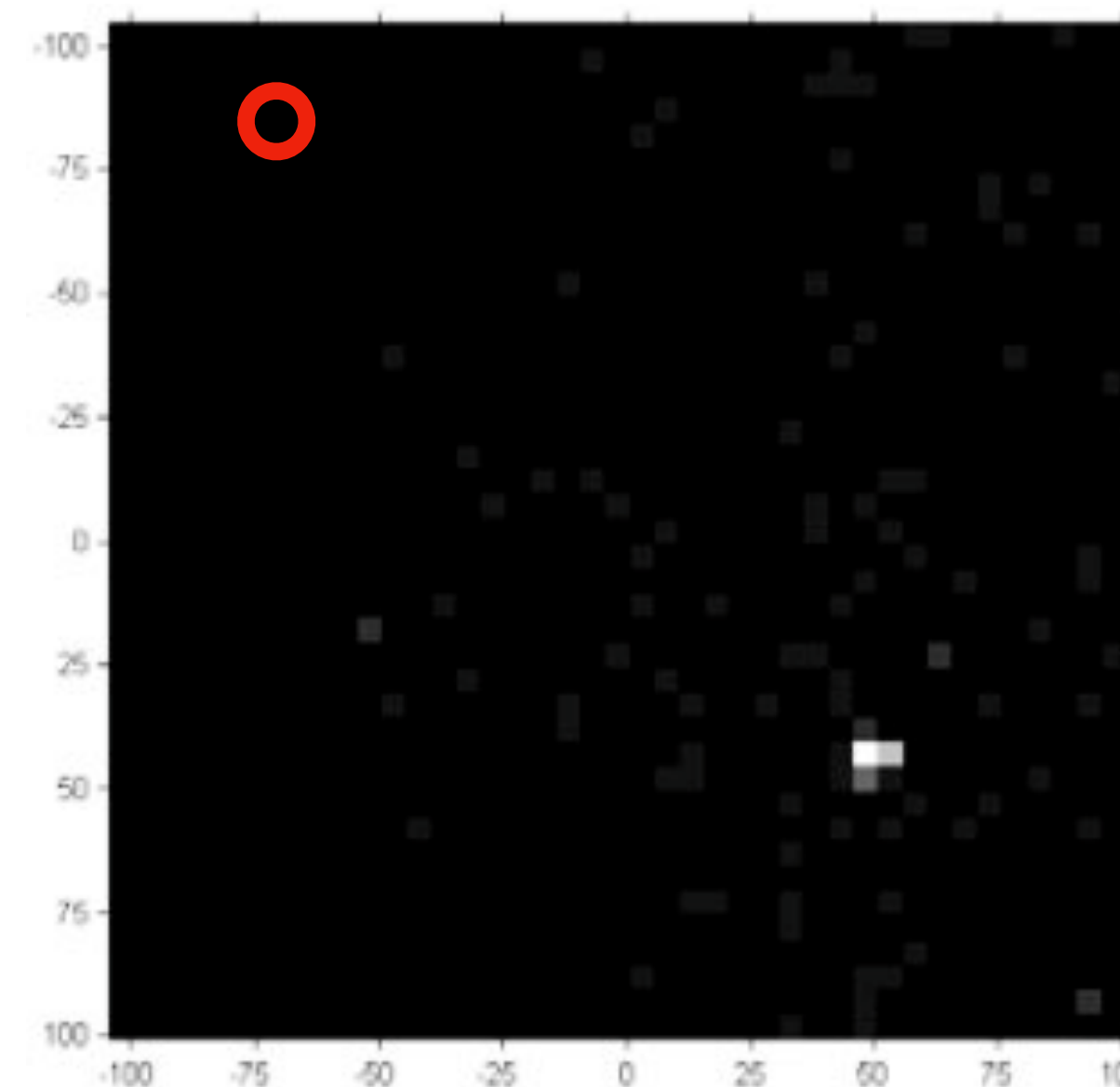
Hough Transform

template



query

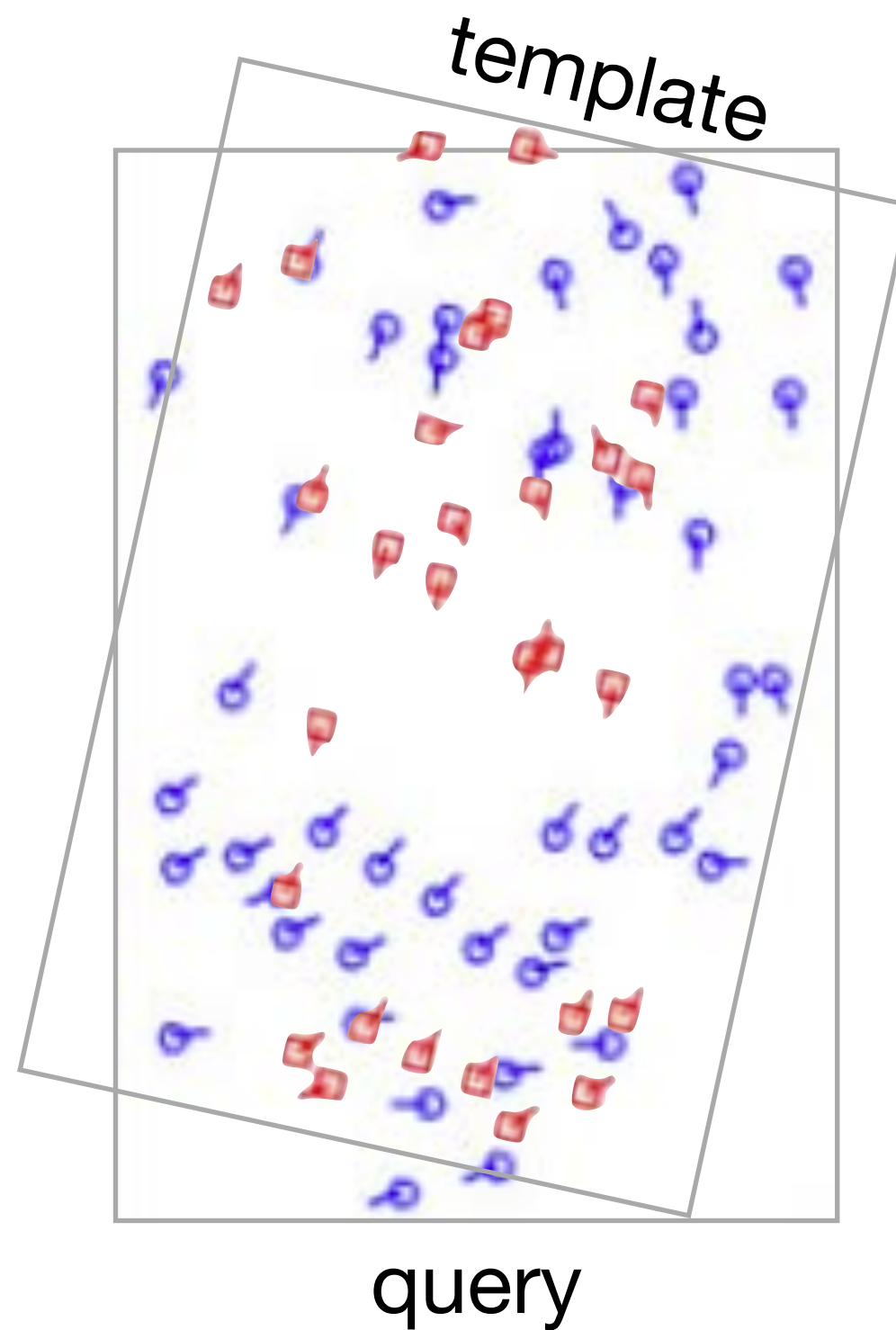
Jain, Ross, and Nadakumar
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Springer Books, 2011



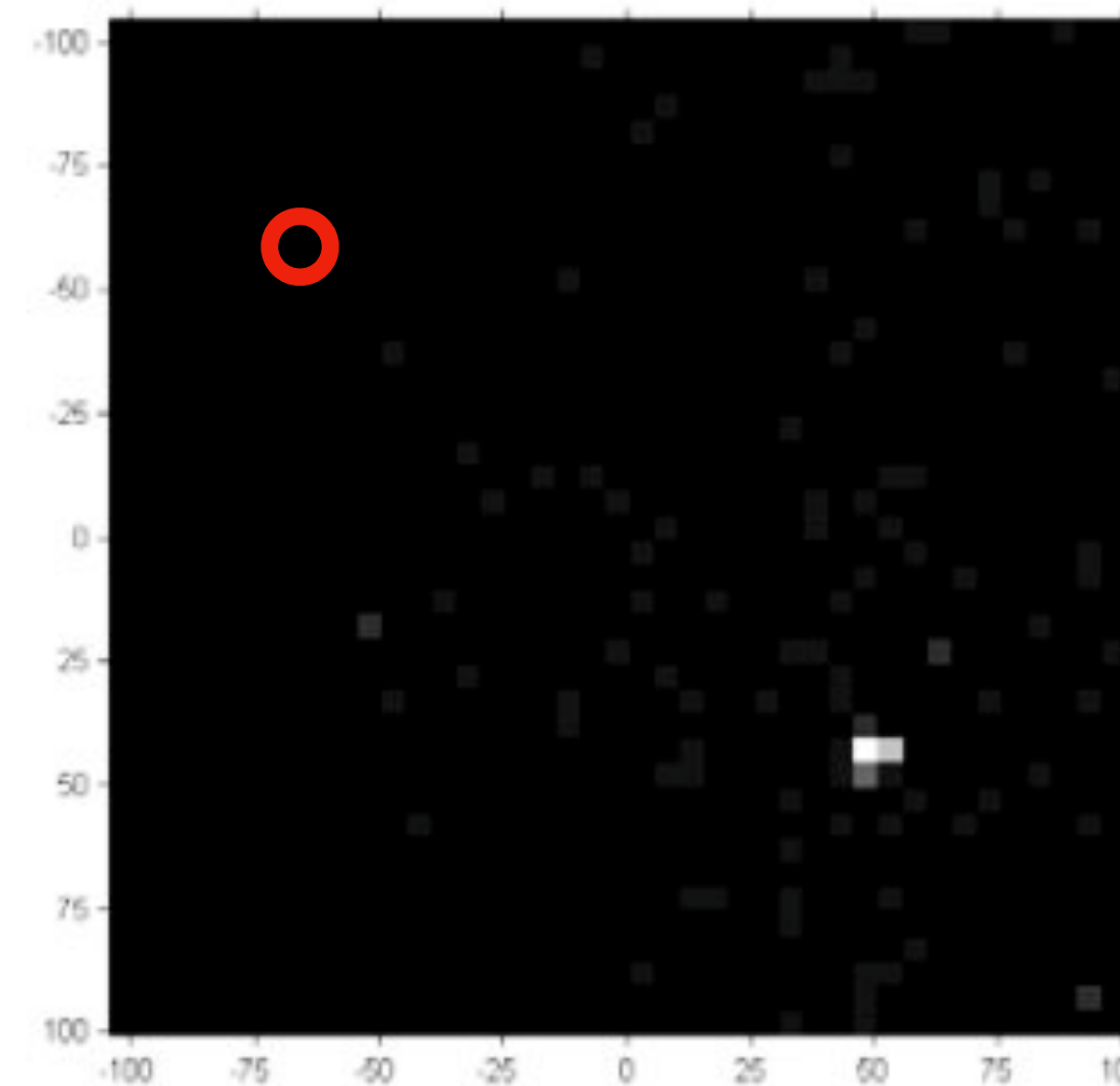
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform



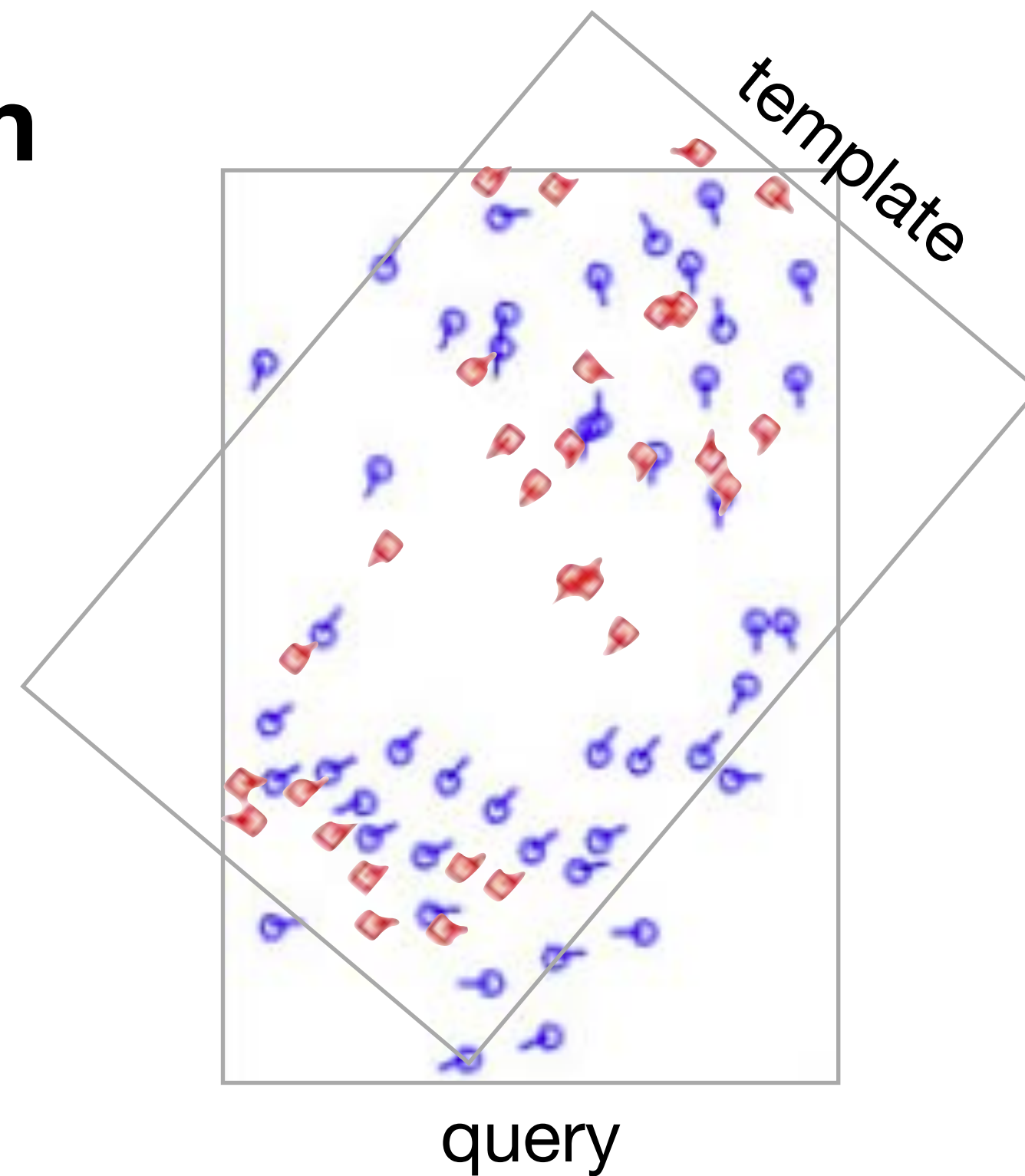
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Springer Books, 2011



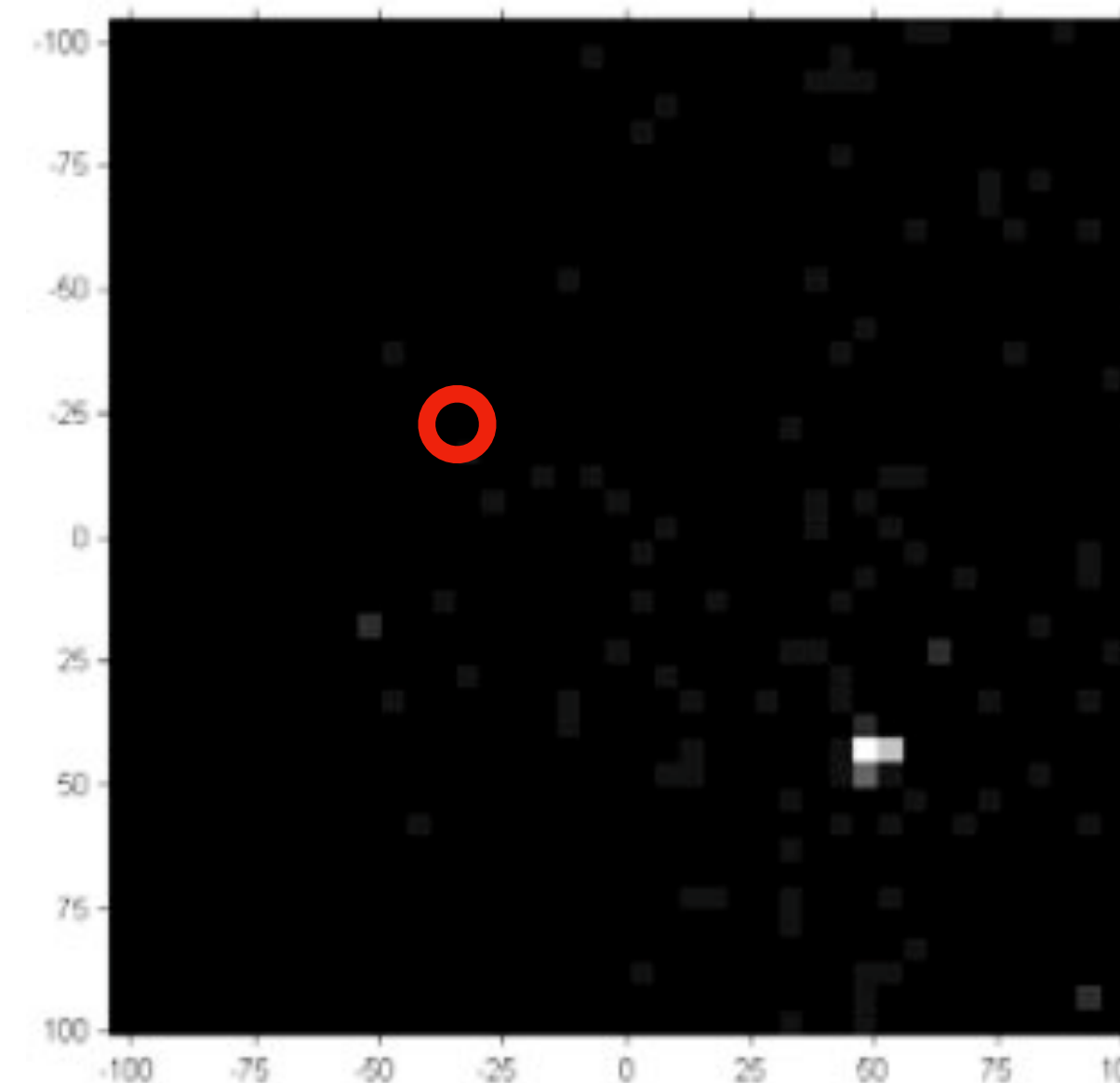
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform



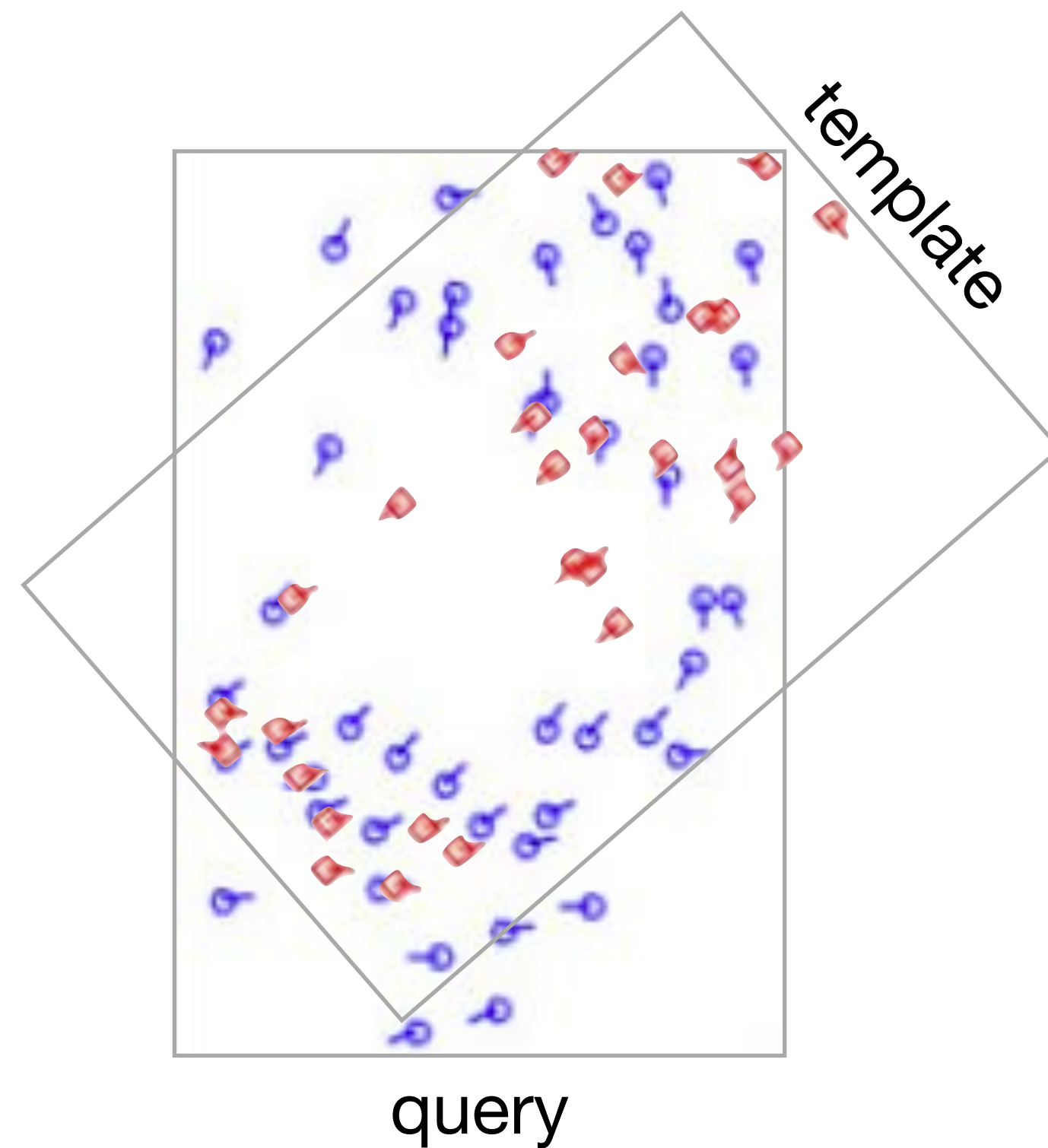
Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011



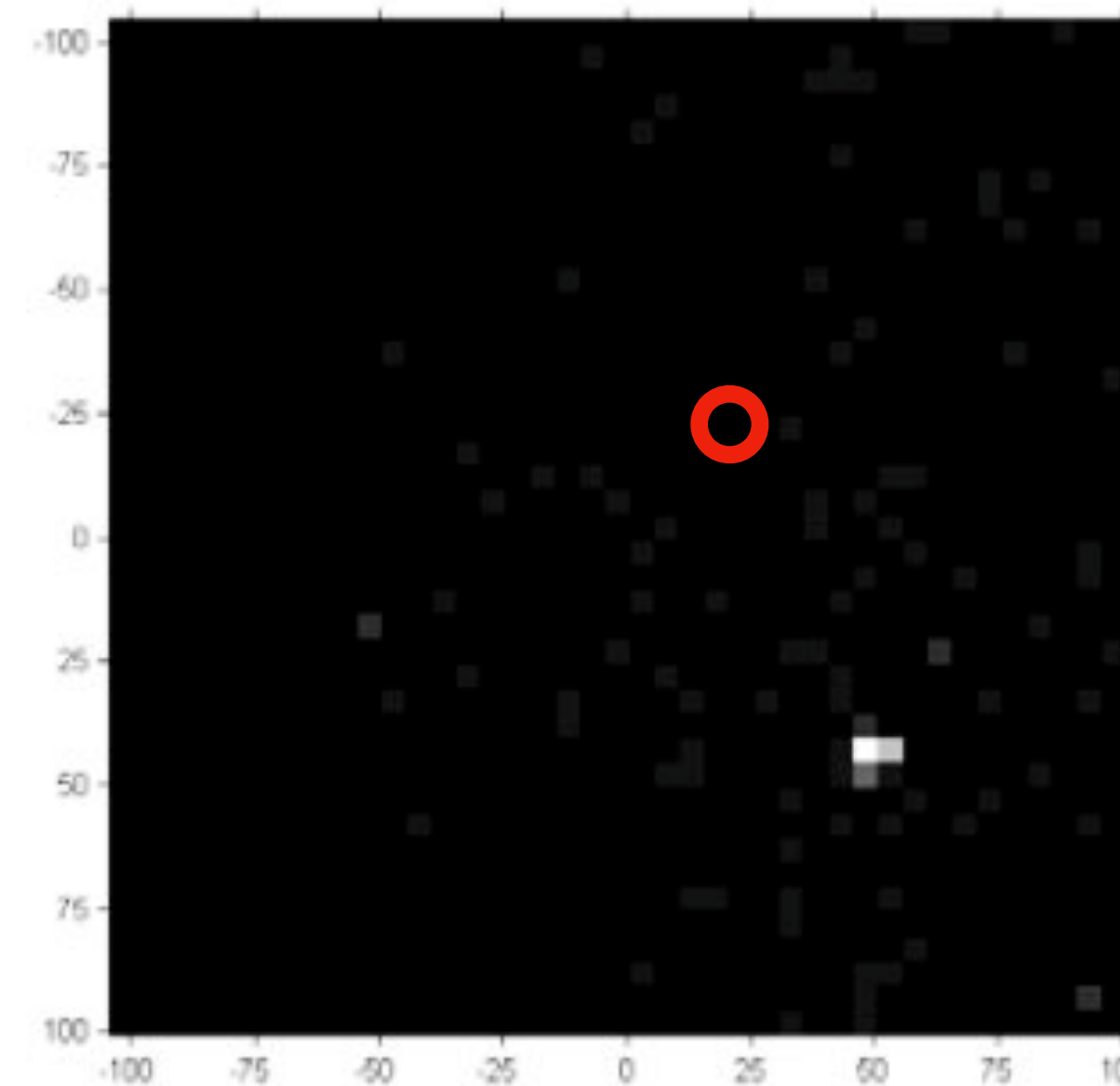
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform



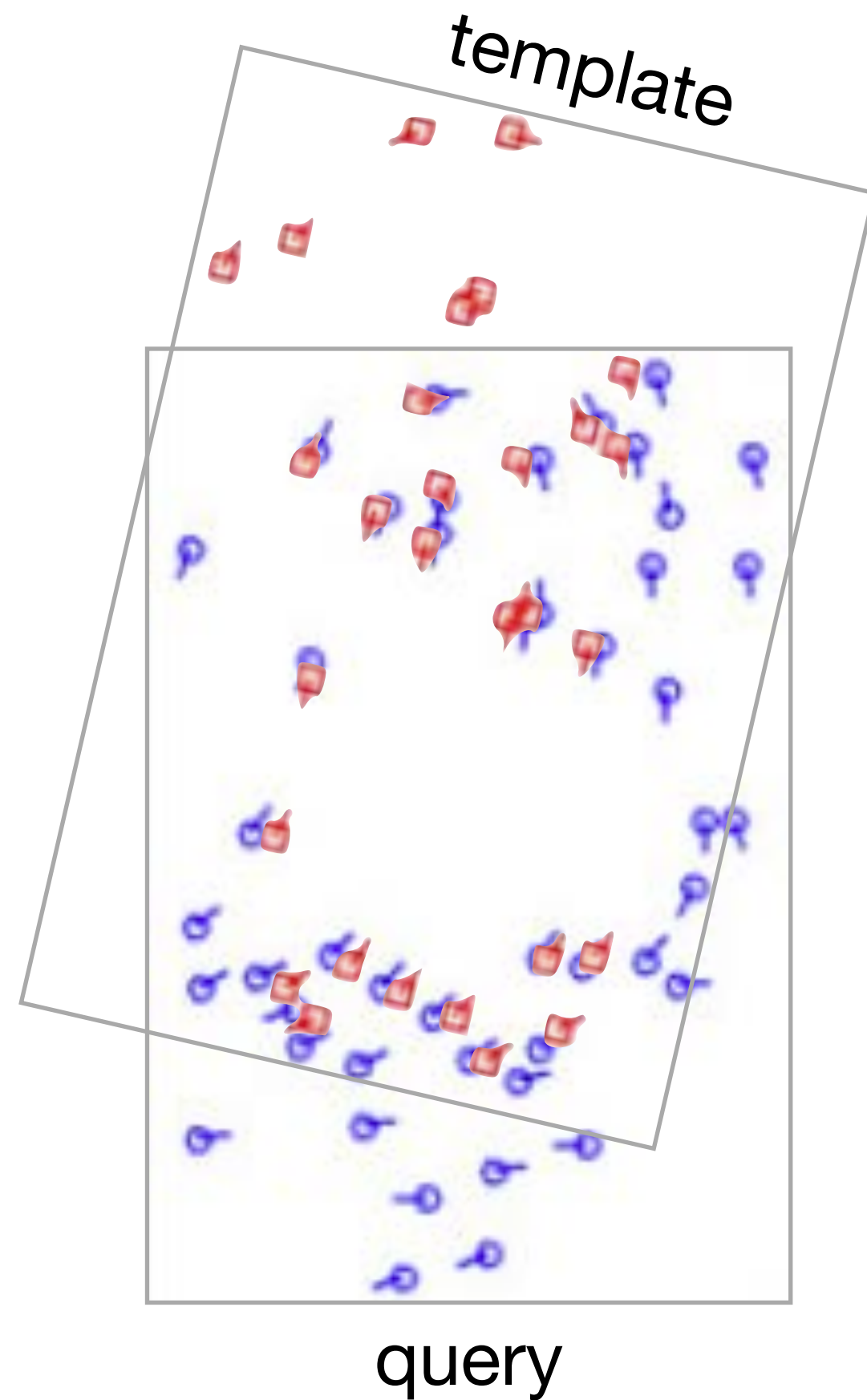
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Springer Books, 2011



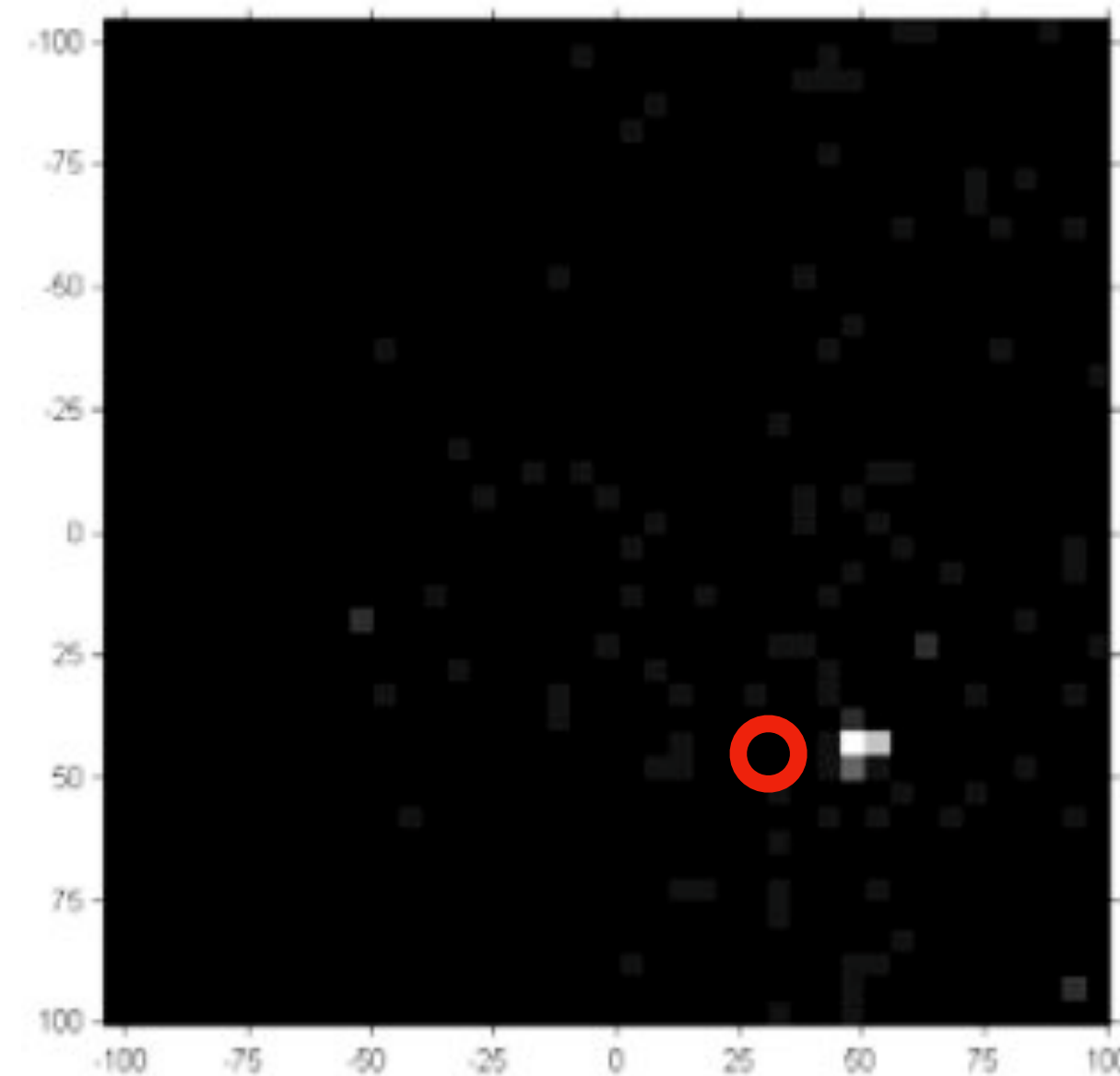
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform



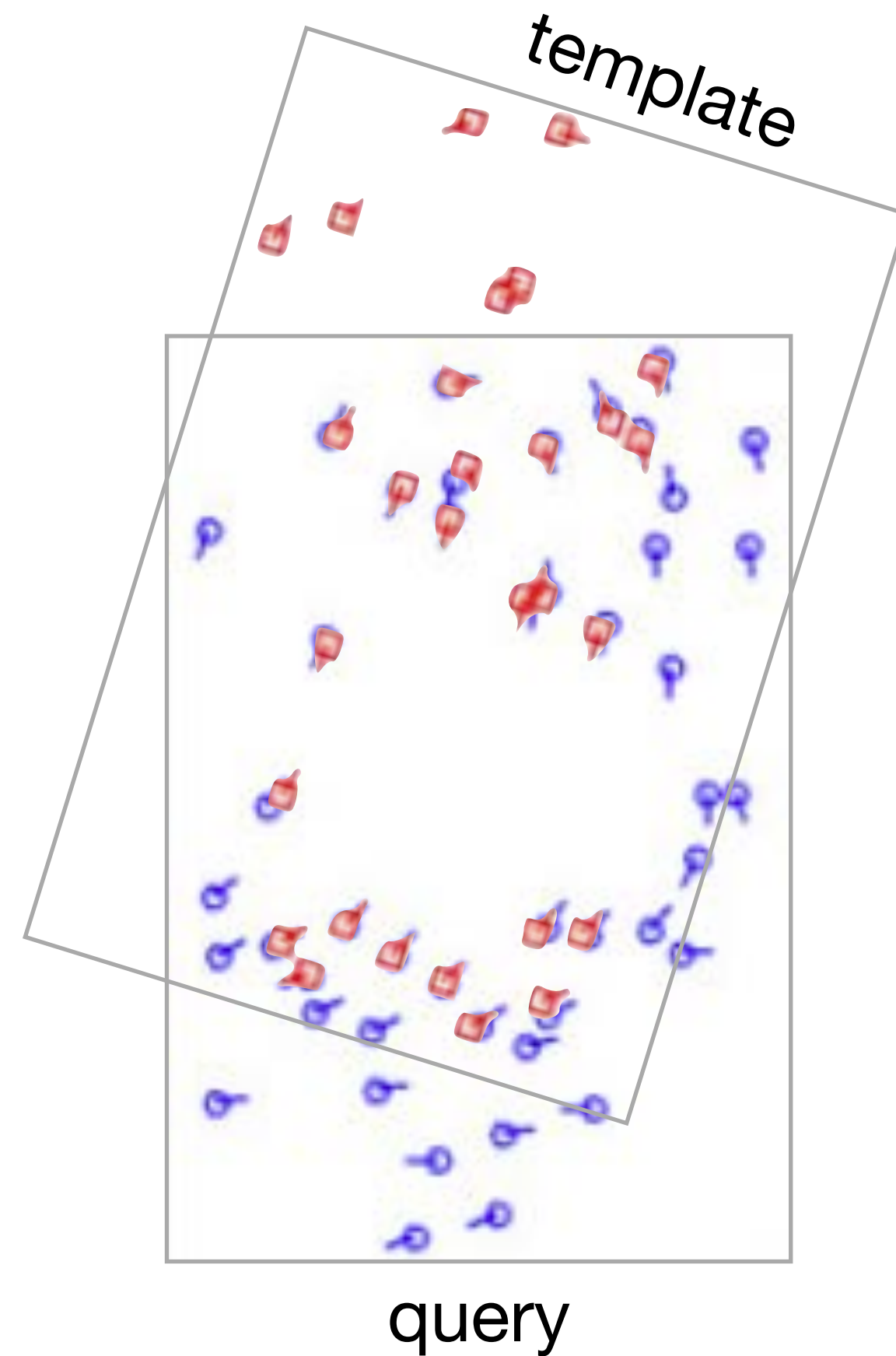
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Springer Books, 2011



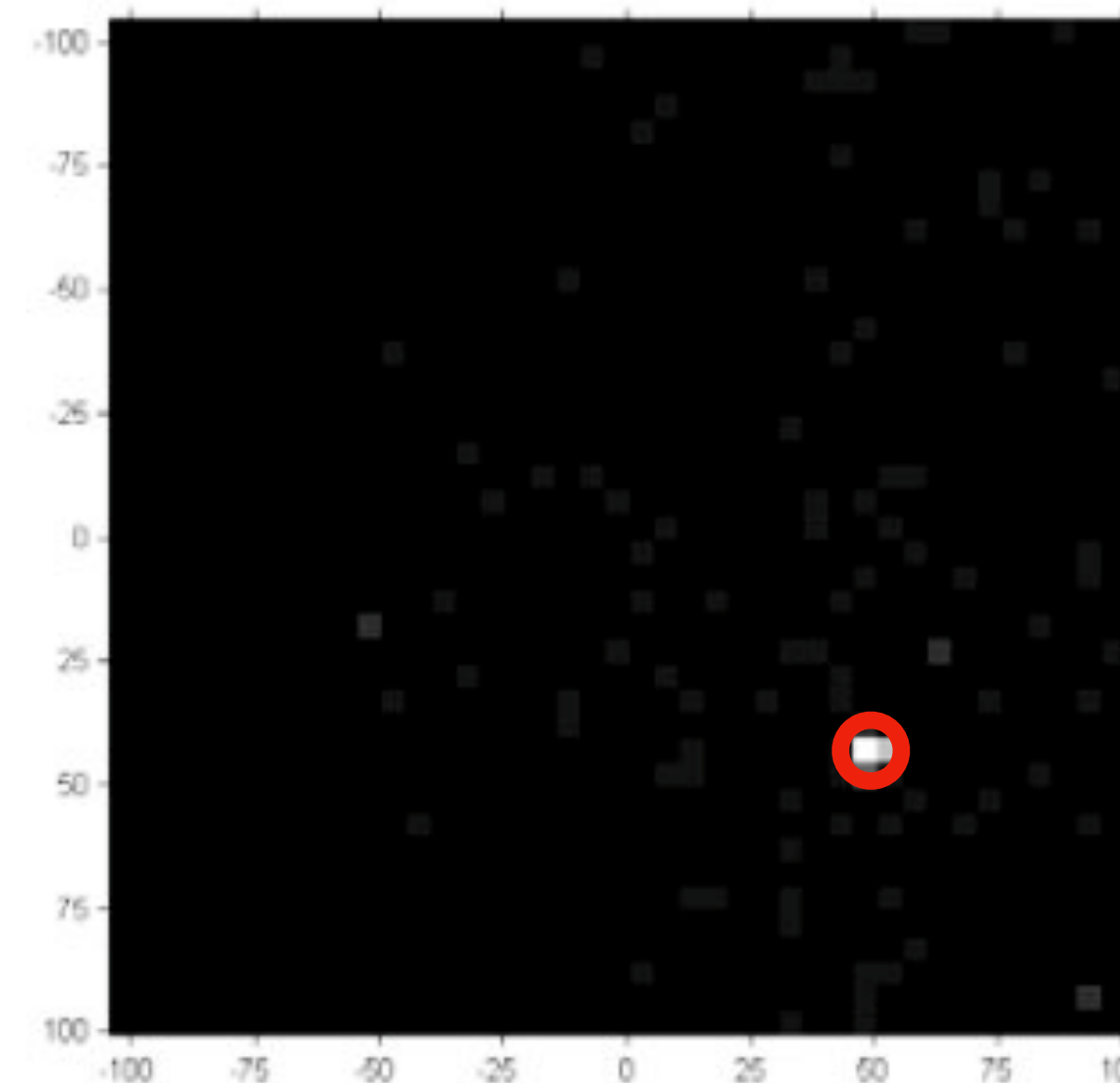
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform



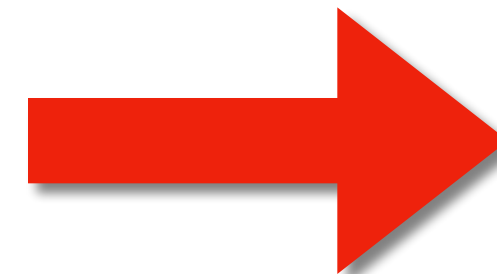
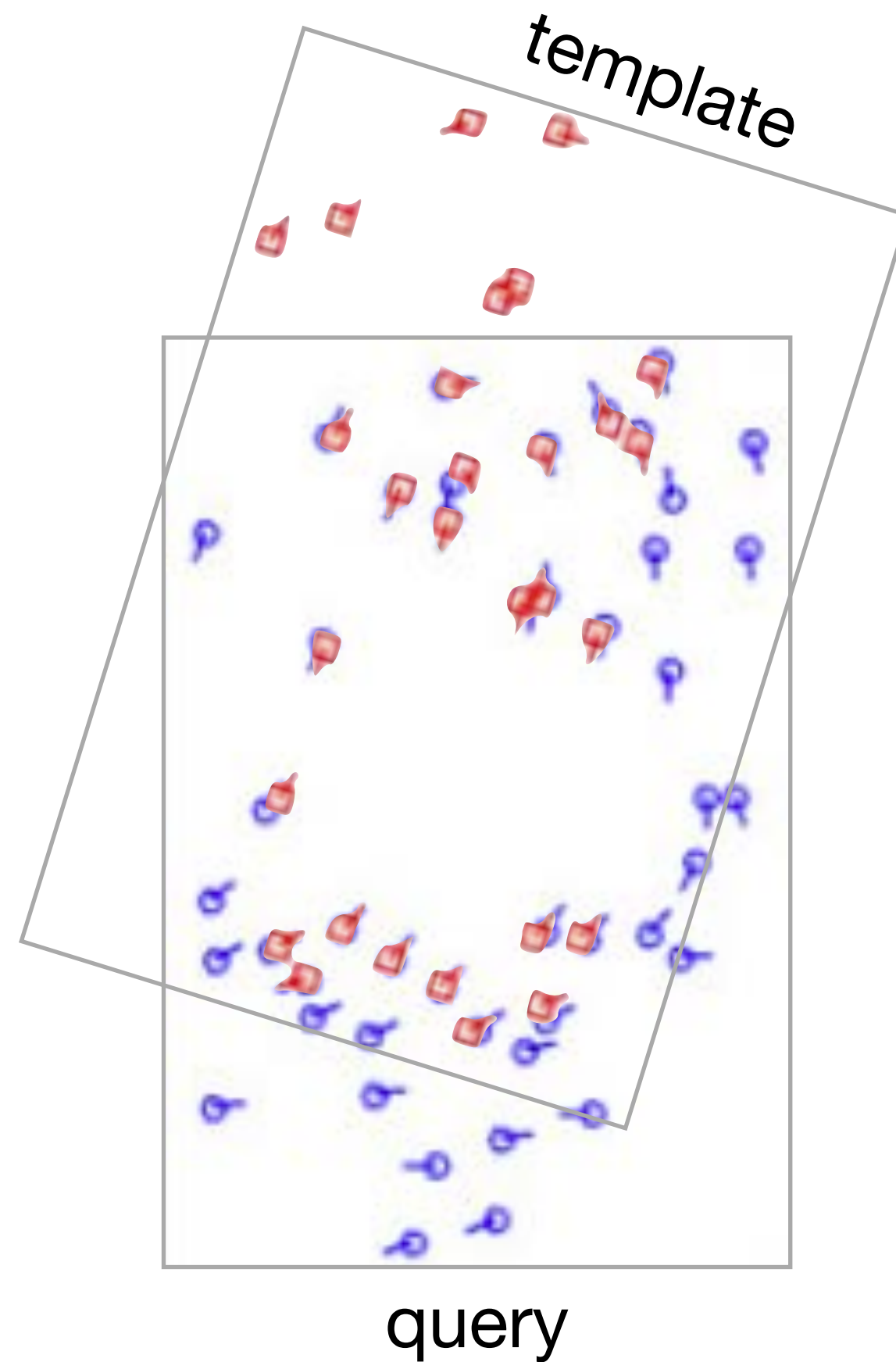
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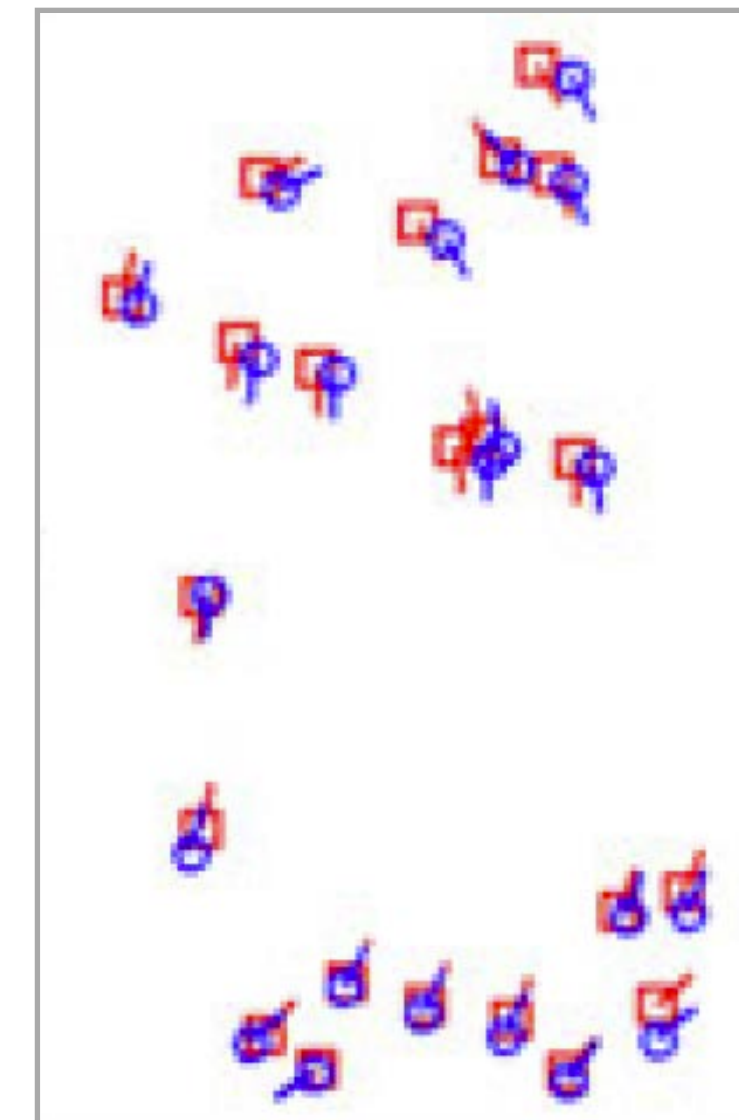
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

Feature Matching

Hough Transform

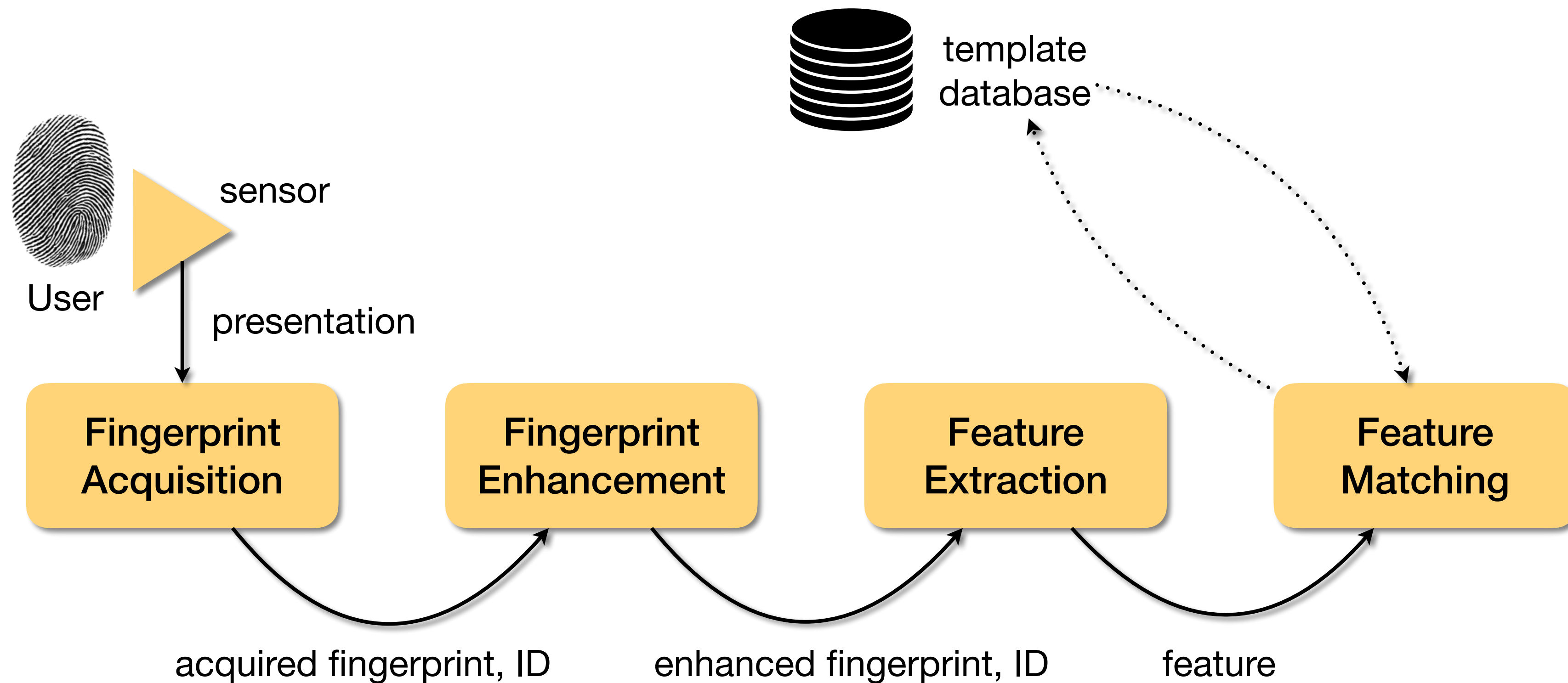


Jain, Ross, and Nadakumar
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Springer Books, 2011

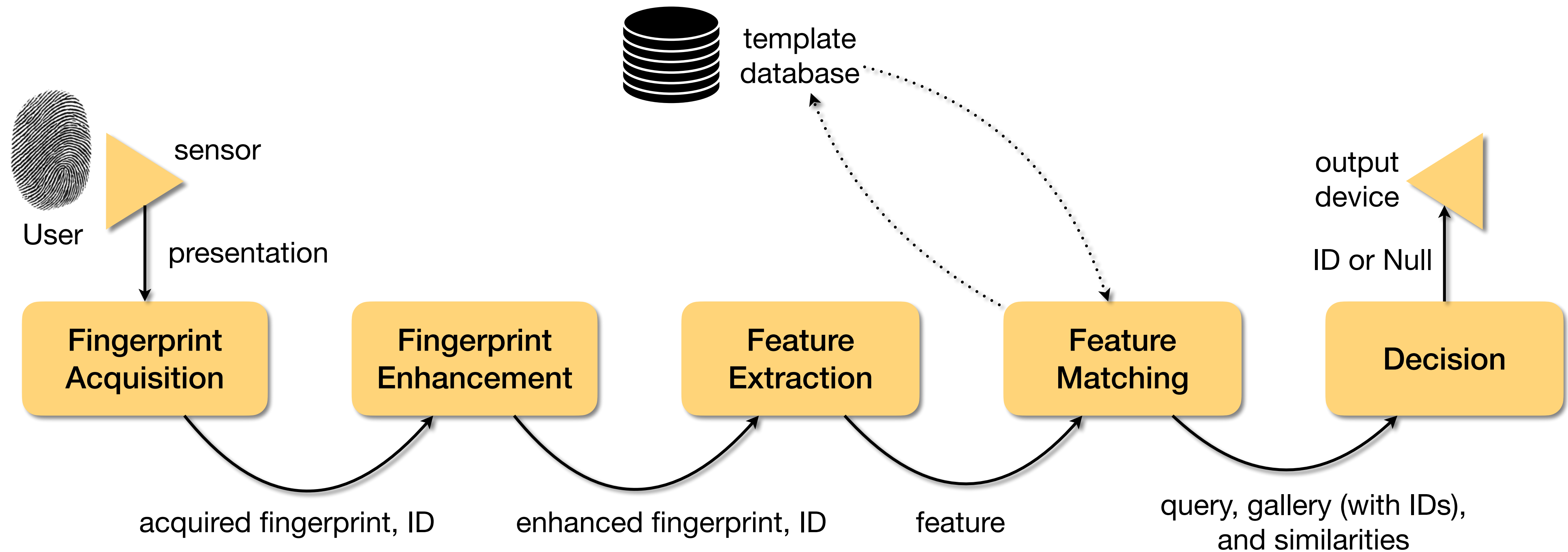


21 matches

Fingerprint Recognition



Fingerprint Recognition



Decision

Similarity-based Decision

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

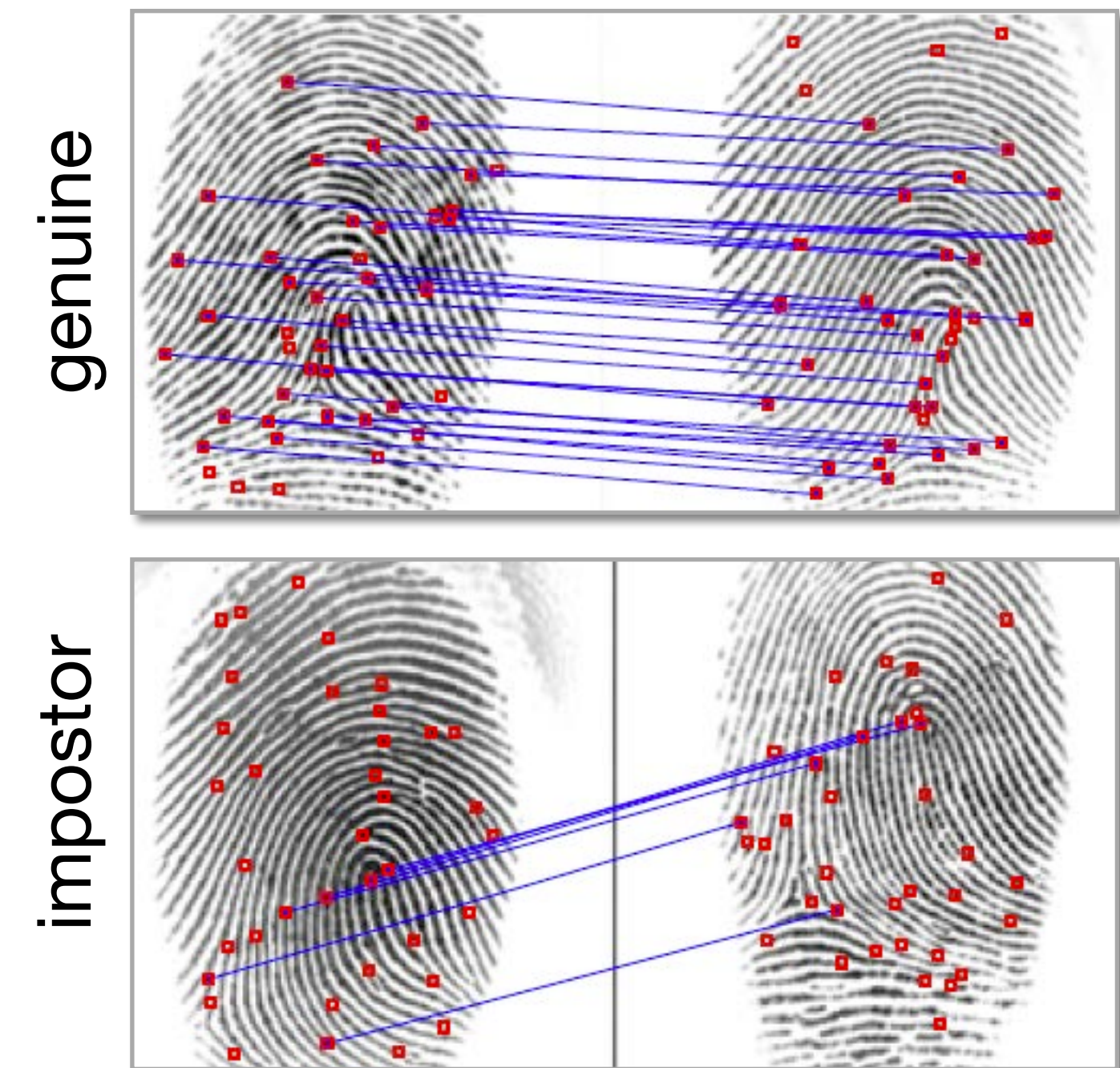
Simple score

Let M be the number of minutiae in image i .

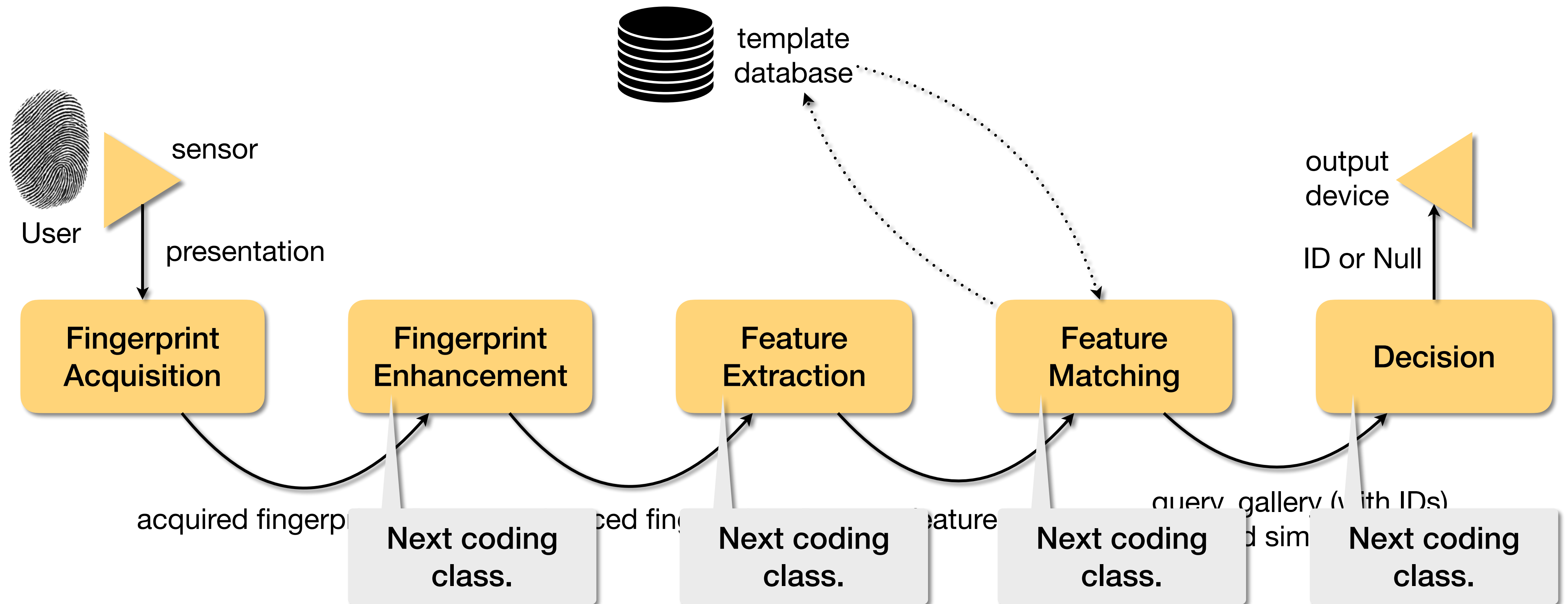
Let N be the number of minutiae in image j .

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

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



Fingerprint Recognition



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/Dv5DsU.

