

# Fingerprint Recognition III

CSE 40537/60537 Biometrics

**Daniel Moreira**  
Spring 2020

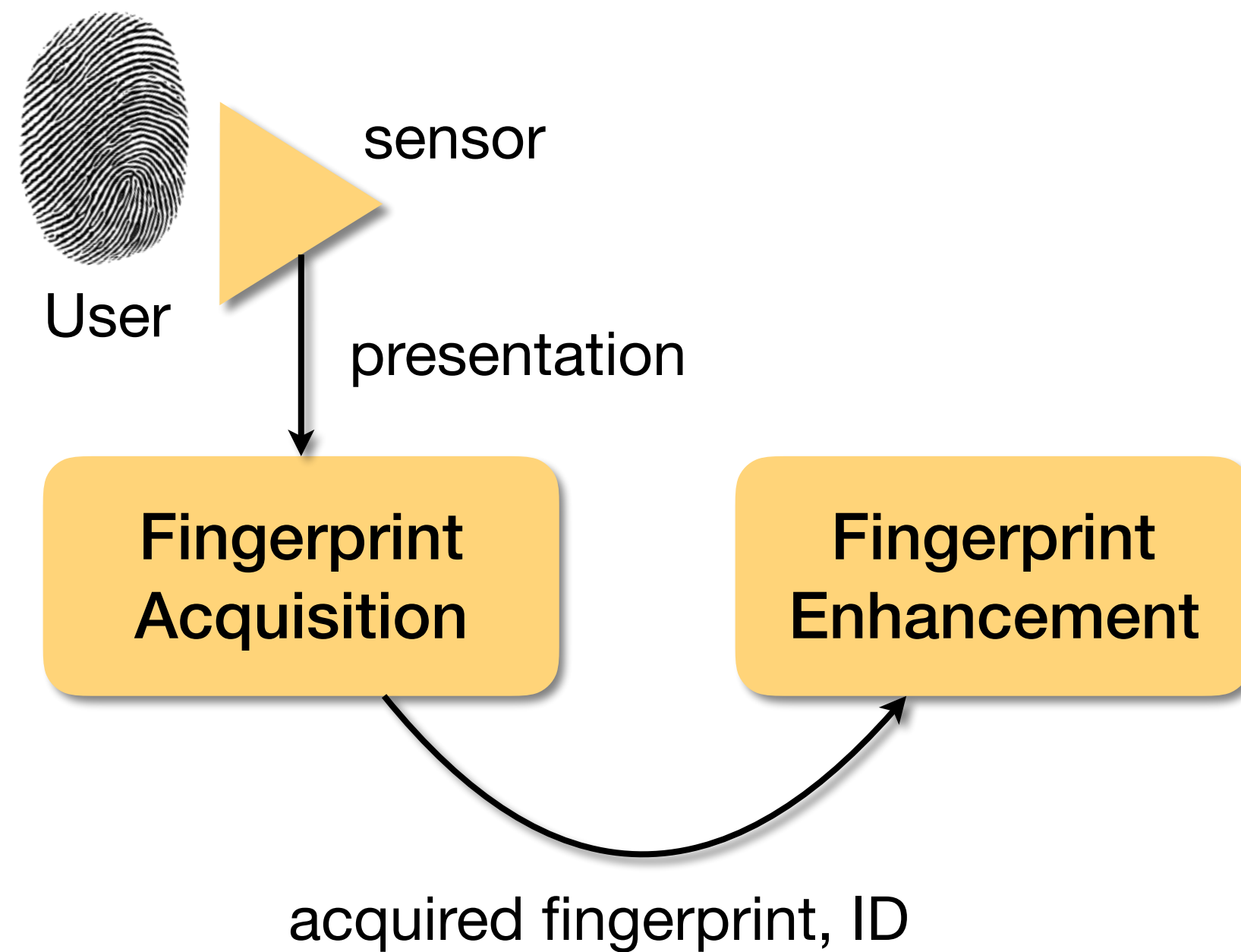


# Today you will...

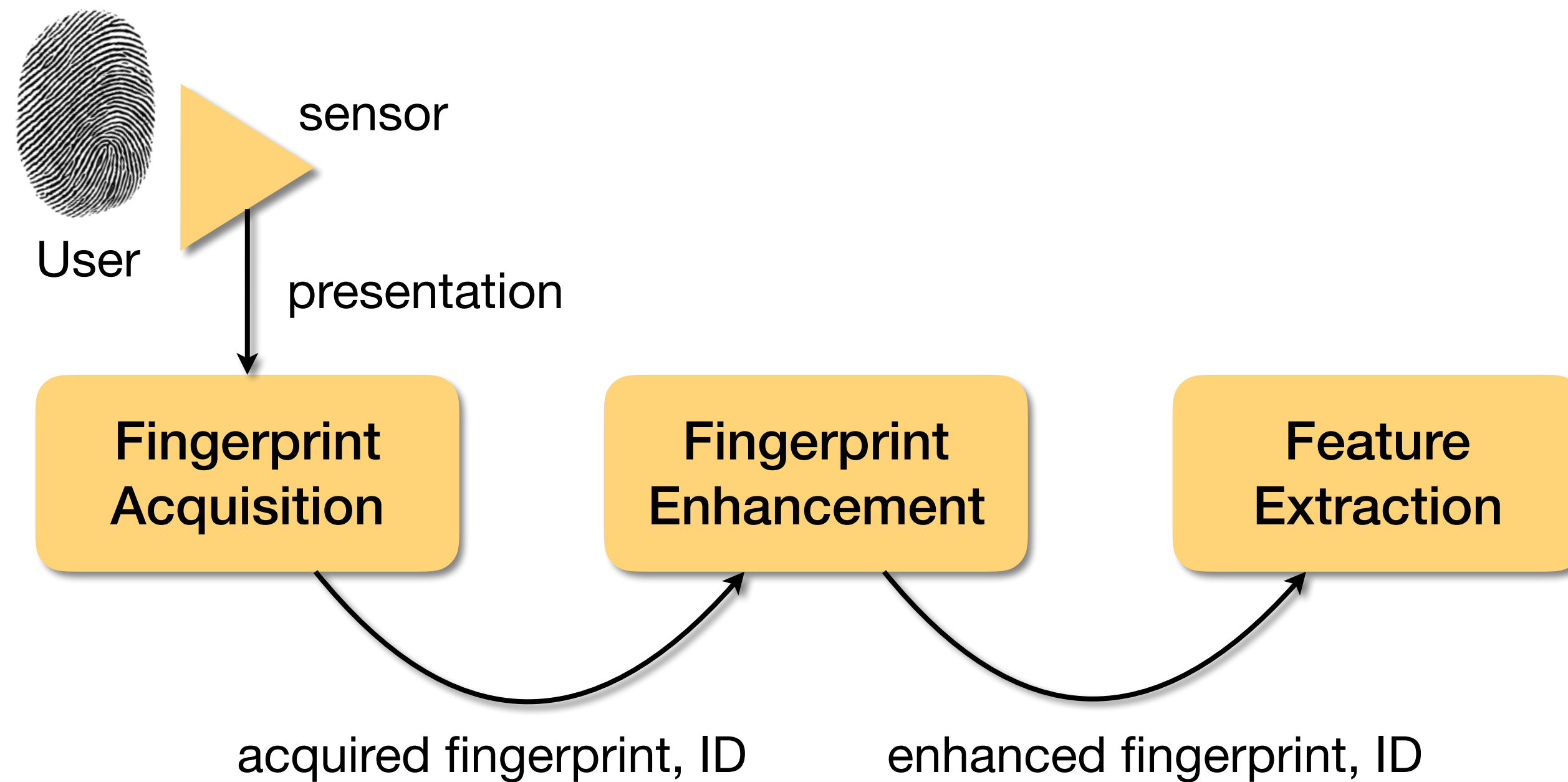
*Get to know*

Minutiae detection, description, and matching.

# 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

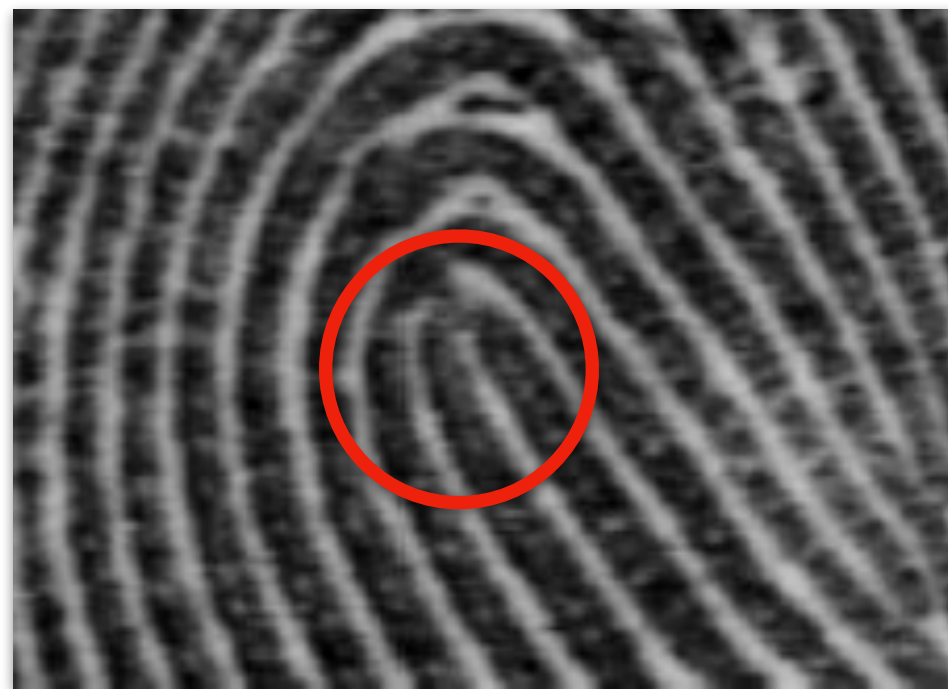
## Level-1 Features

Singular points and core.

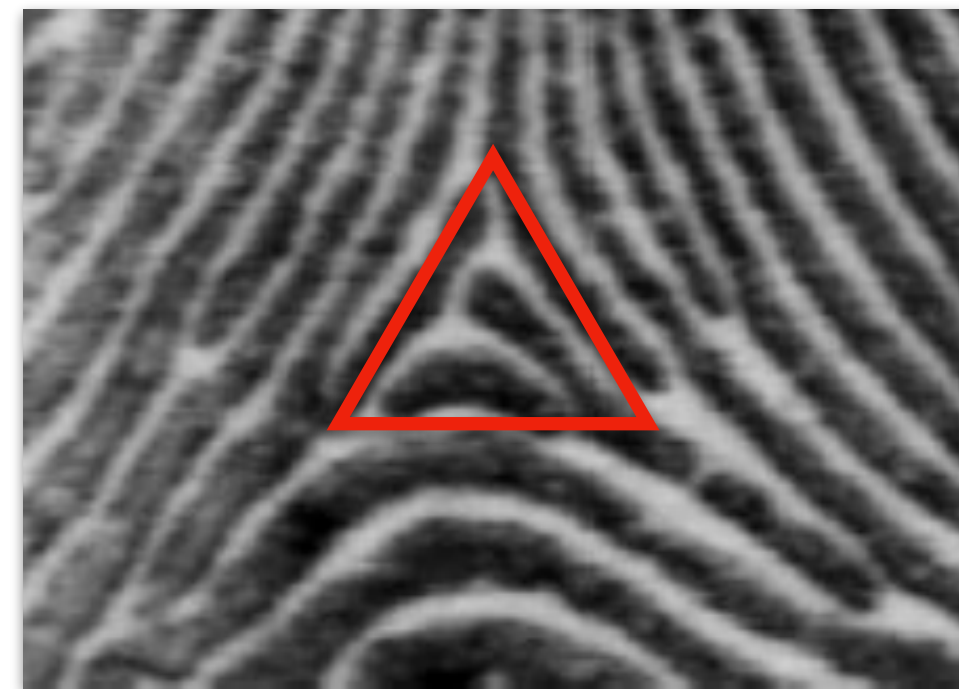
Recommended capture resolution: 250 ppi (pixels per inch).

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.



# Features

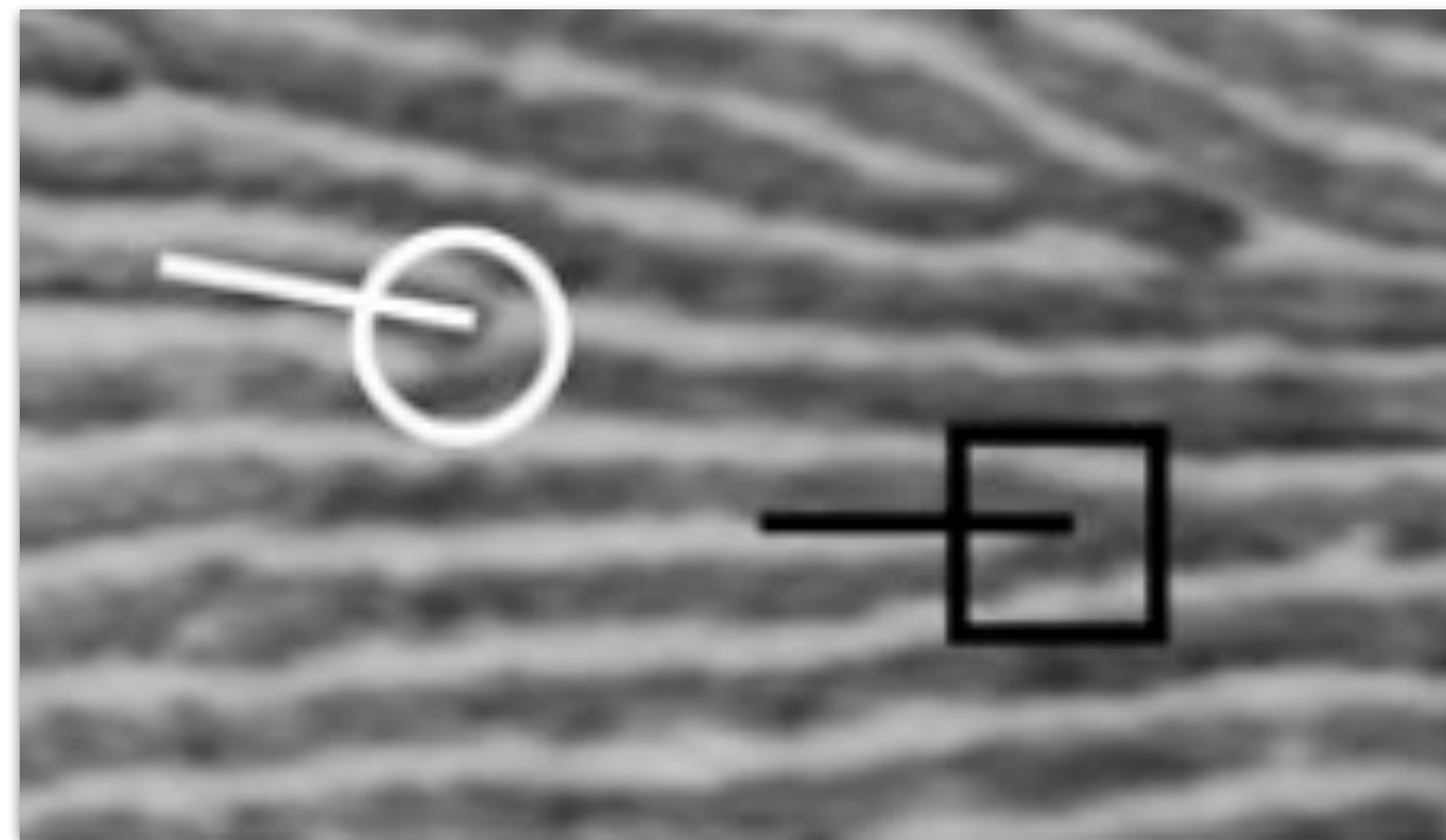
## Level-2 Features

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

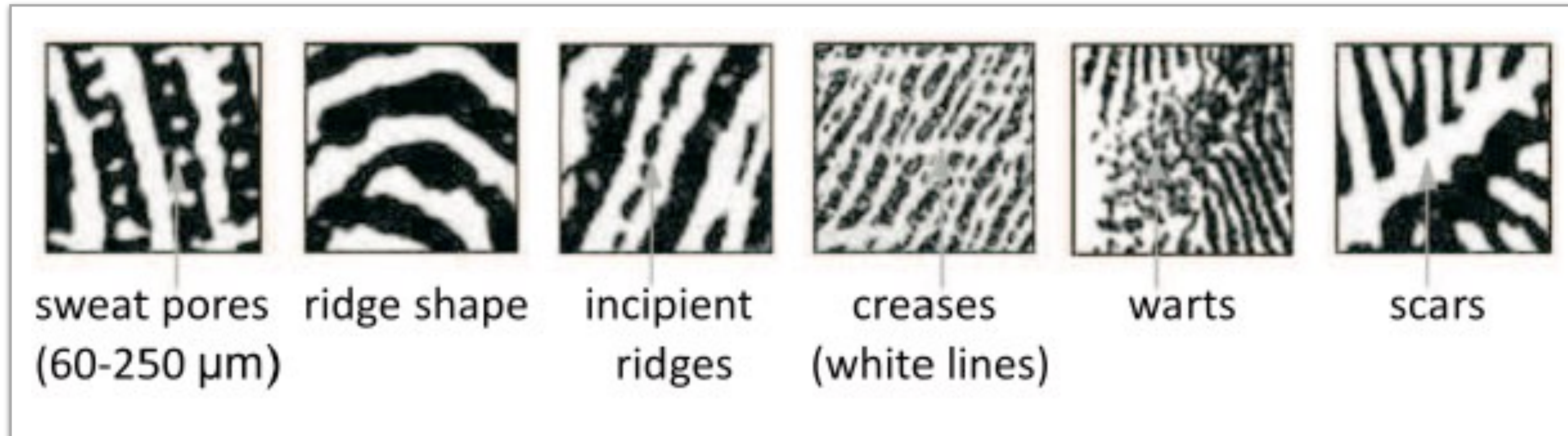
# Features

## 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...

# Feature Extraction

## But First, Further References for Level-1 Features

Jain, Ross, and Nandakumar  
*Introduction to Biometrics,*  
*Section 2.4.2*  
Springer Books, 2011

## Level-3 Features

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...



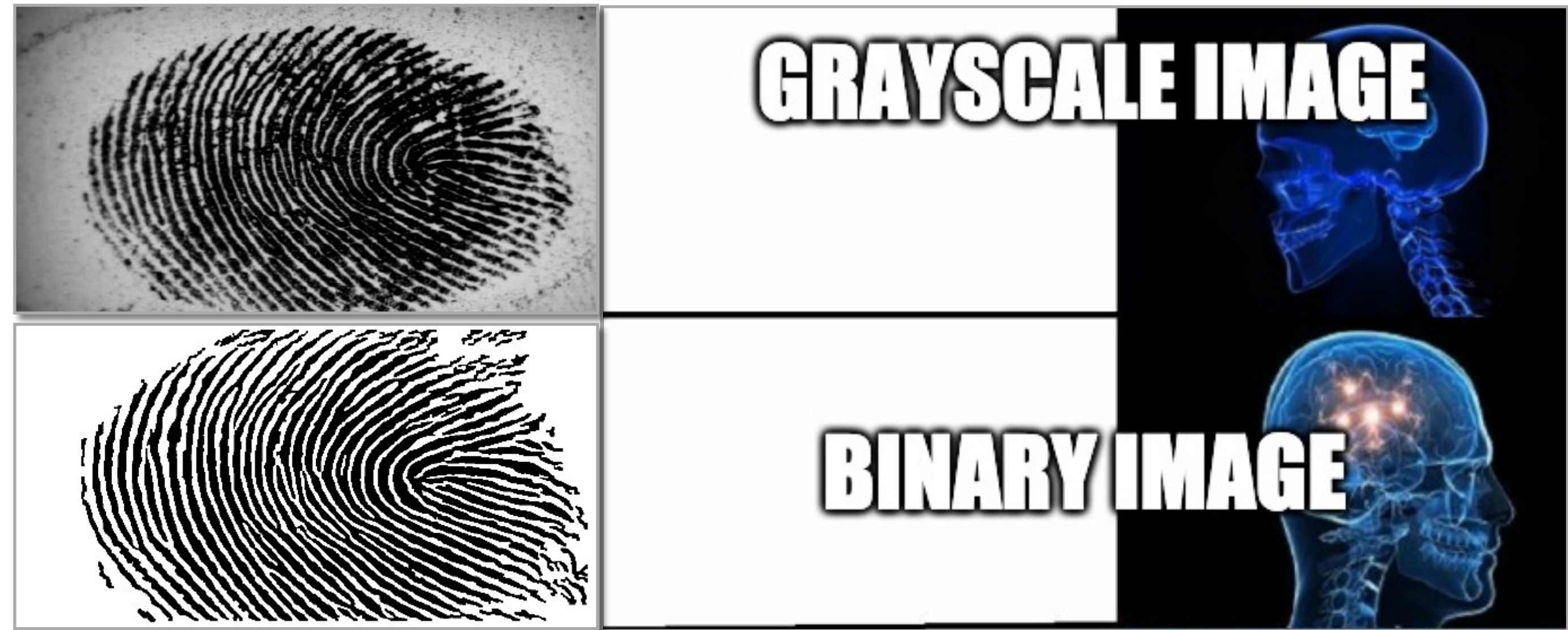
# Minutiae Detection

**Three Strategies**  
Start from...



# Minutiae Detection

**Three Strategies**  
Start from...

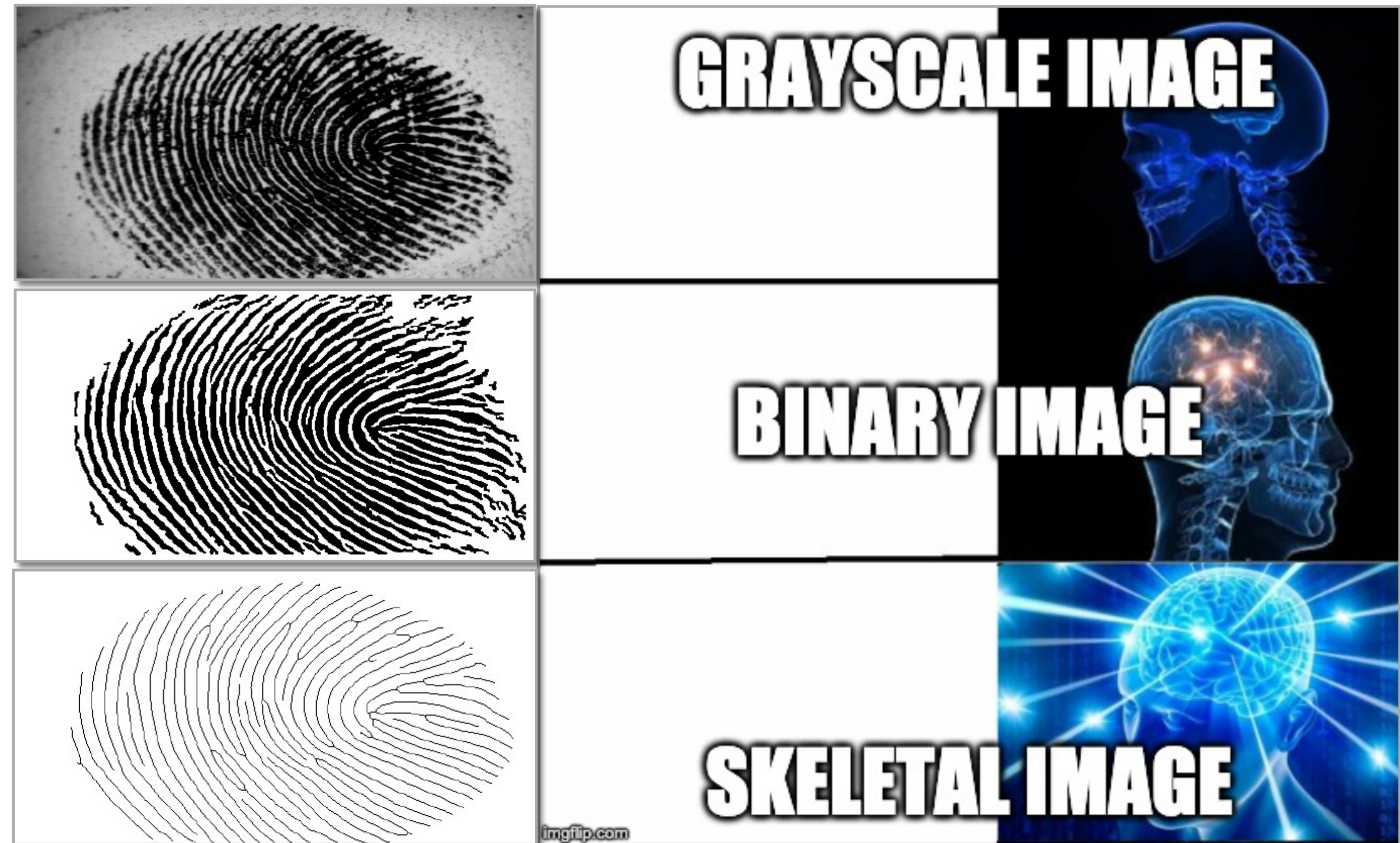




# Minutiae Detection

## Three Strategies

Start from...



Source: Dr. Adam Czajka



# Minutiae Detection

## Three Strategies

Start from...

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



Source: Dr. Adam Czajka



# 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



# 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

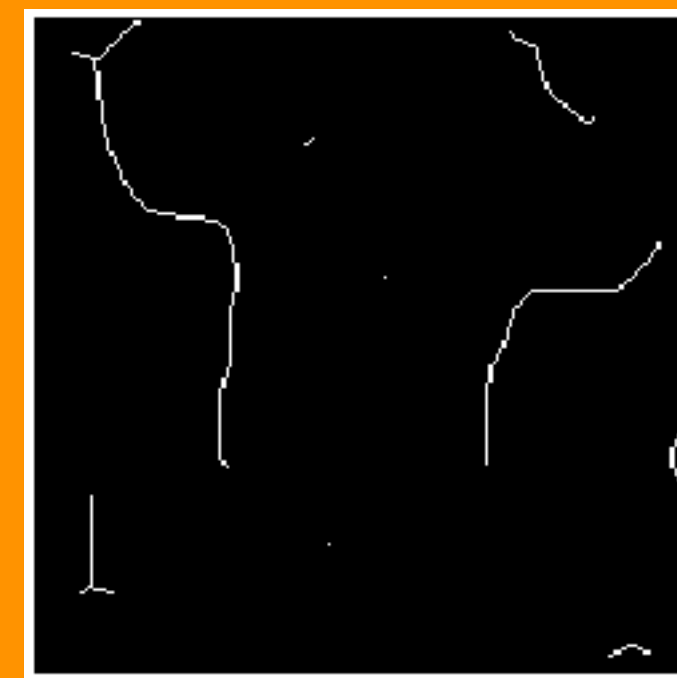
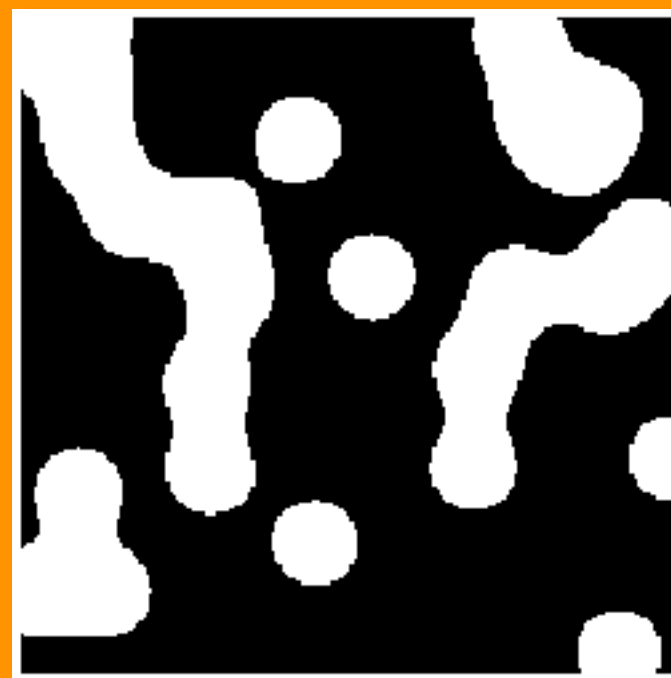
## Skeletal Images

Need for binarization enhancement followed by skeletonization enhancement.

## How to perform skeletonization?

### Image Processing

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

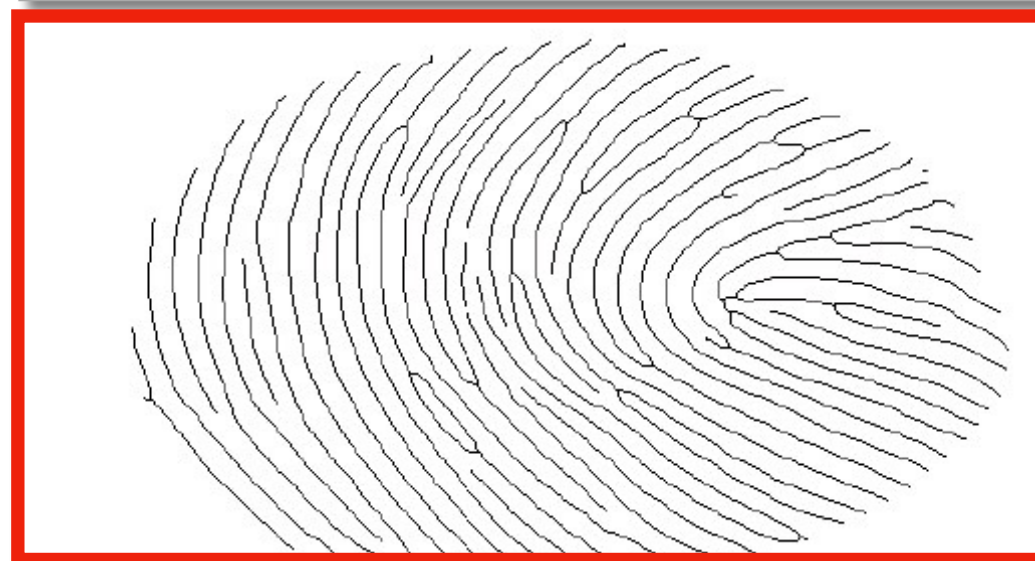


Source: [https://scikit-image.org/docs/dev/auto\\_examples/edges/plot\\_skeleton.html](https://scikit-image.org/docs/dev/auto_examples/edges/plot_skeleton.html)



# Minutiae Detection

## Three Strategies



Source: Dr. Adam Czajka



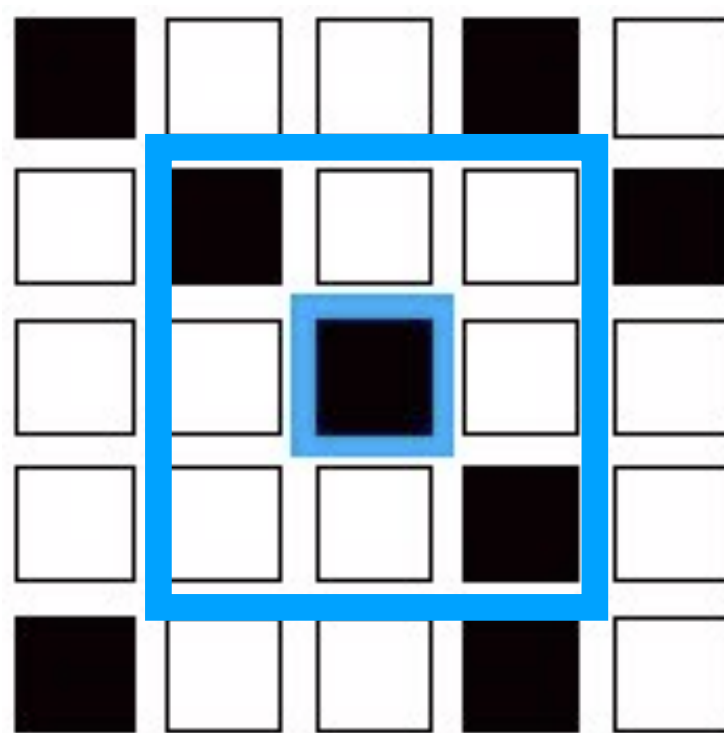
Let's dive into it...



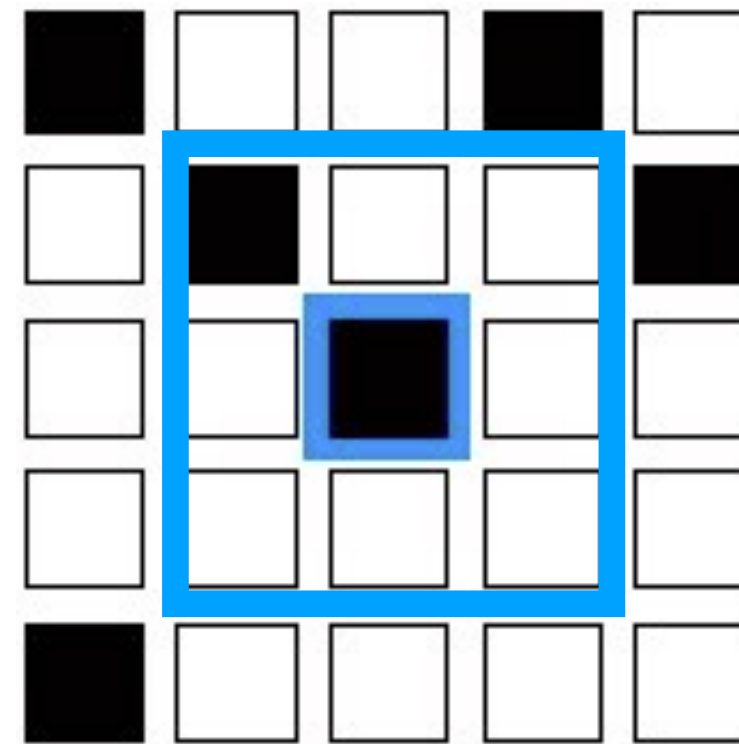
# Minutiae Detection

## Skeletal Images

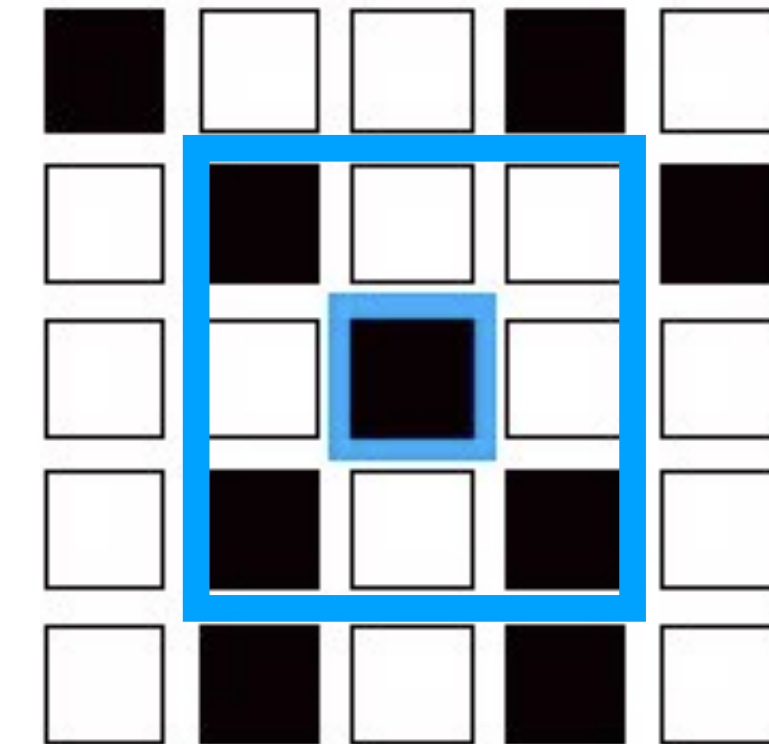
Analyze each ridge pixel neighborhood.  
Count the number of ridge pixels ( $\#RP$ ).



$\#RP = 3$   
No minutiae



$\#RP < 3$   
Ridge end



$\#RP > 3$   
Ridge bifurcation

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



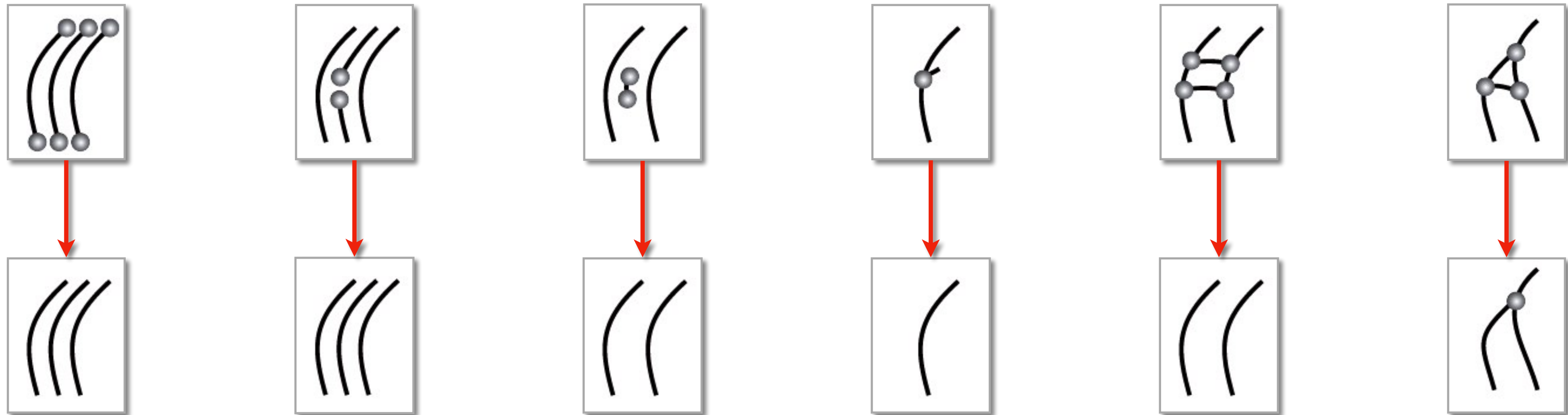
# Minutiae Detection

## Skeletal Images

Remove false positive minutiae.

Example Heuristics:

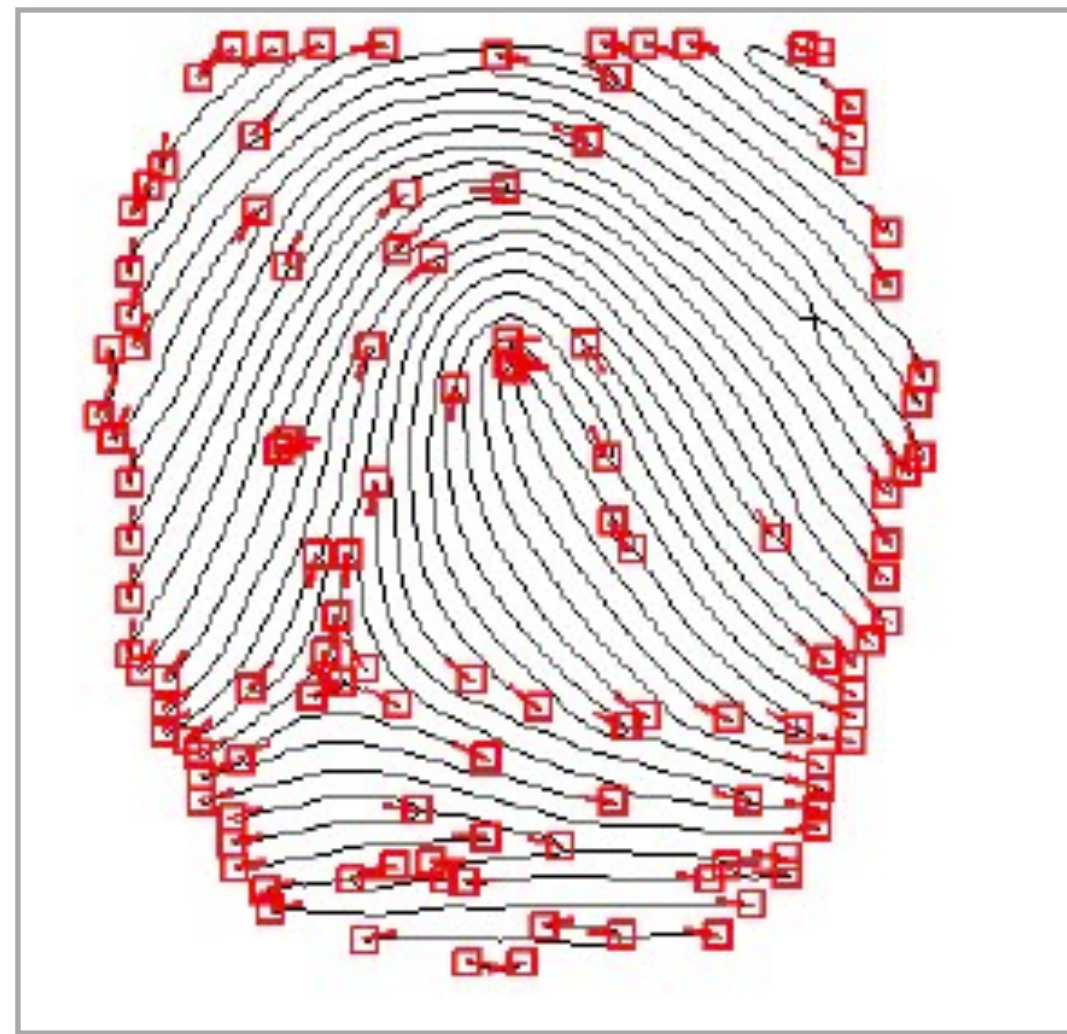
Source: Dr. Adam Czajka



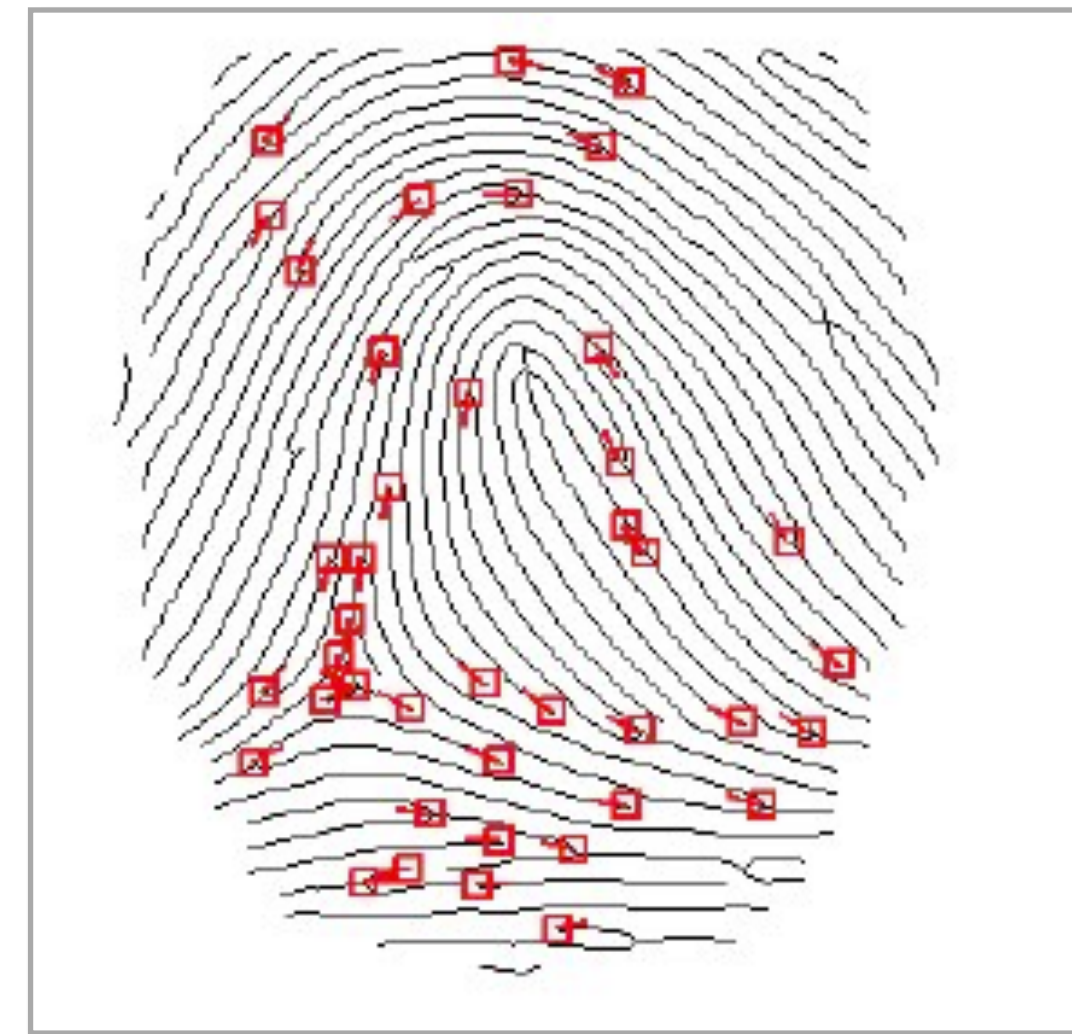
# Minutiae Detection

## Skeletal Images

Remove false positive minutiae.



before



after

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



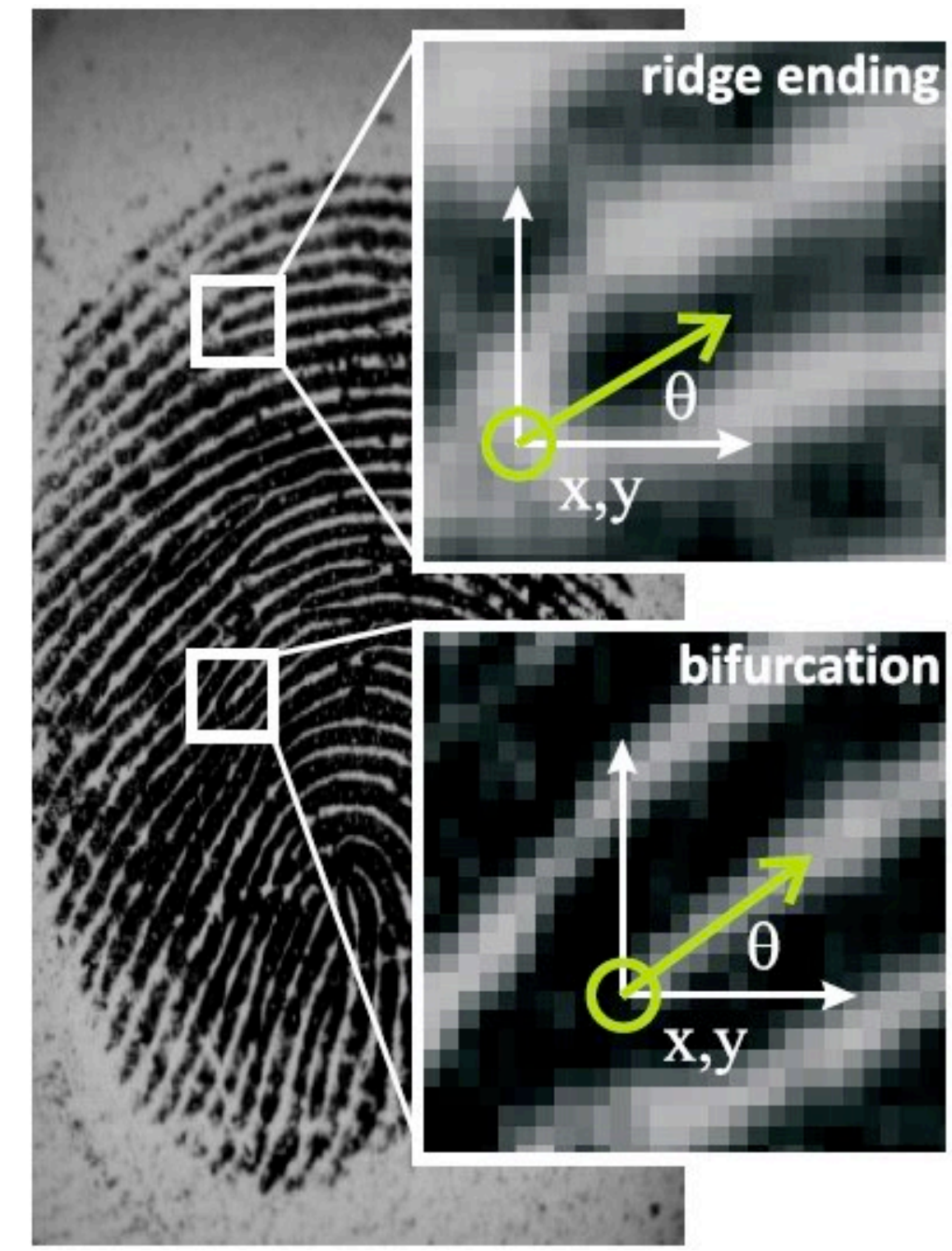
# Minutiae Description

## ISO/IEC FDIS 19794-2 (2011)

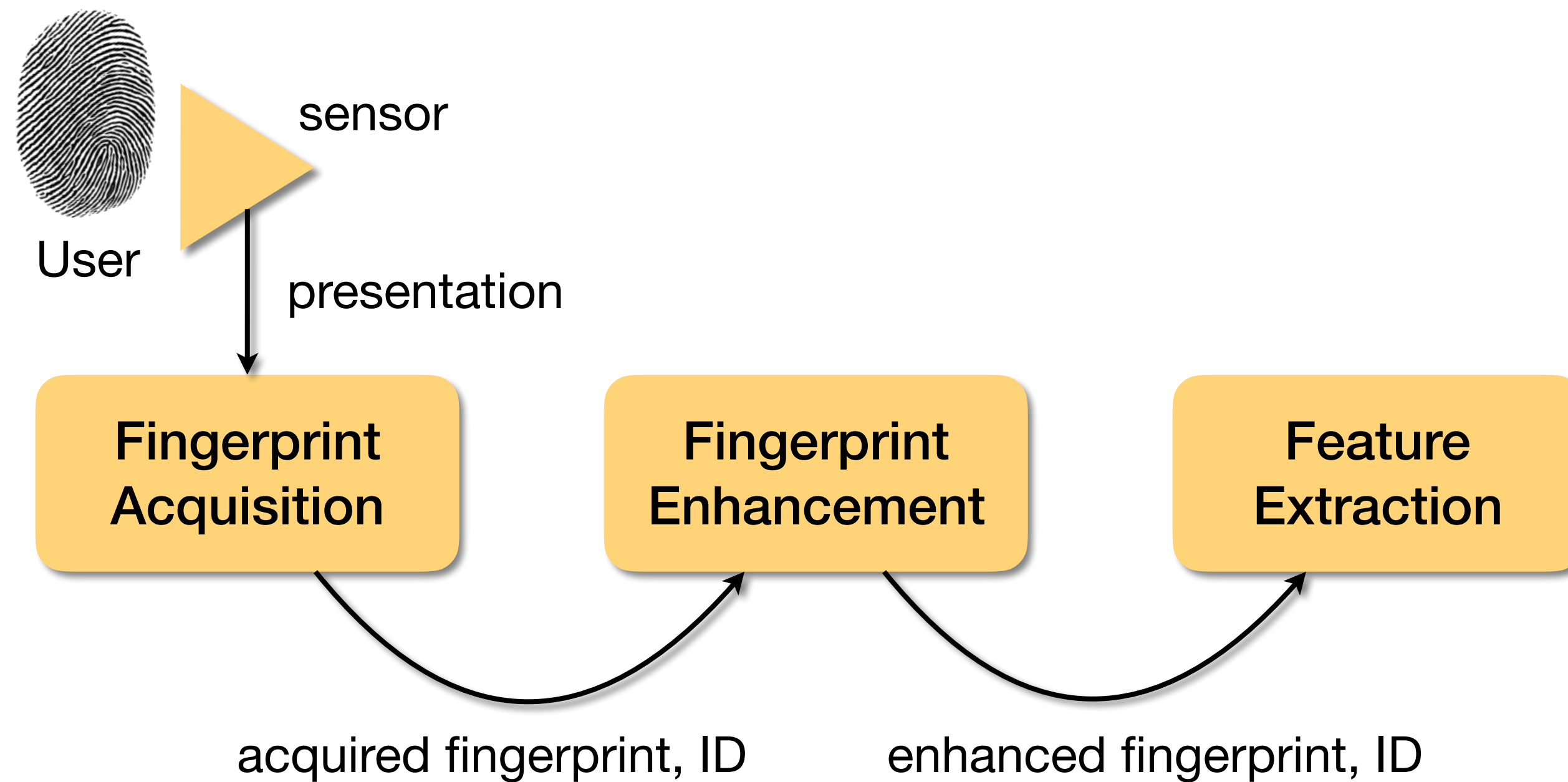
For each minutiae,  
store position  $(x, y)$  and  
angle  $\theta$ .

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

Source: Dr. Adam Czajka

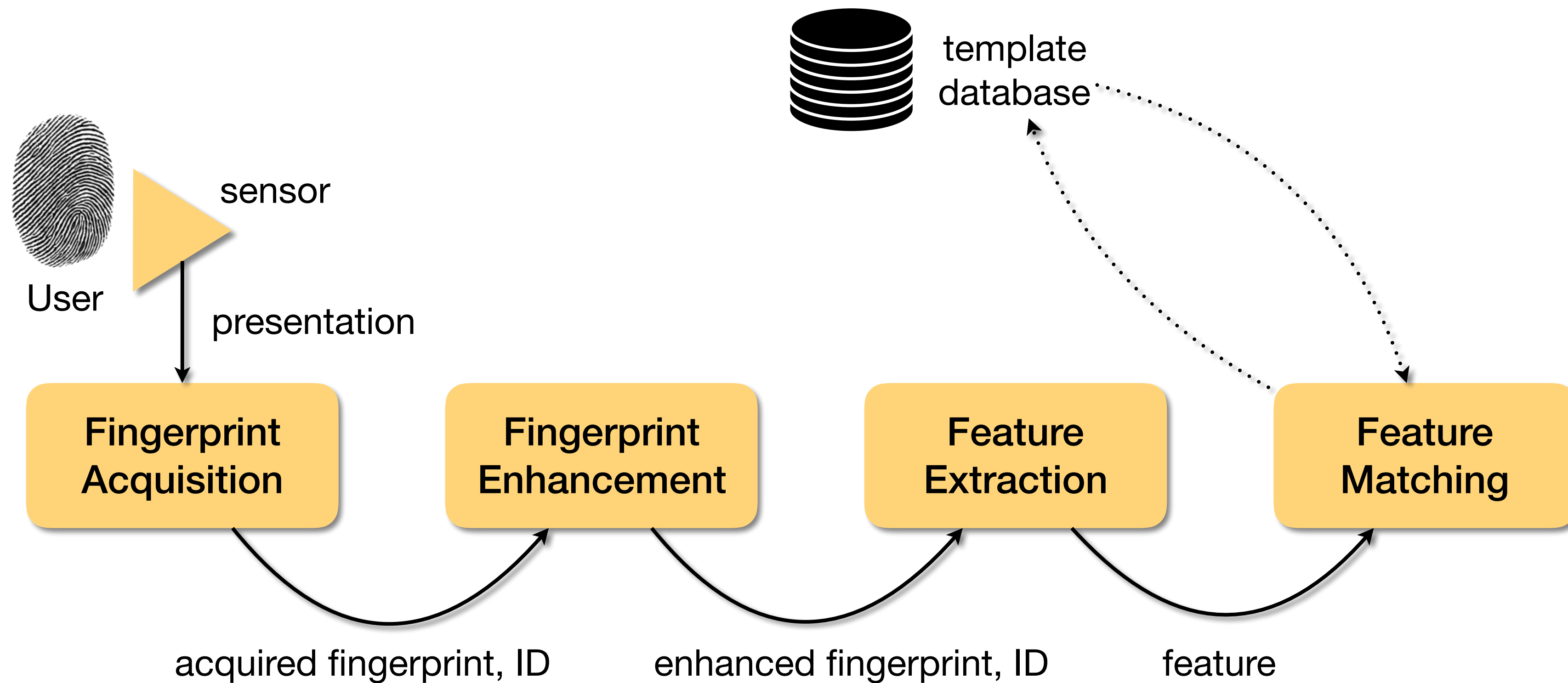


# Fingerprint Recognition





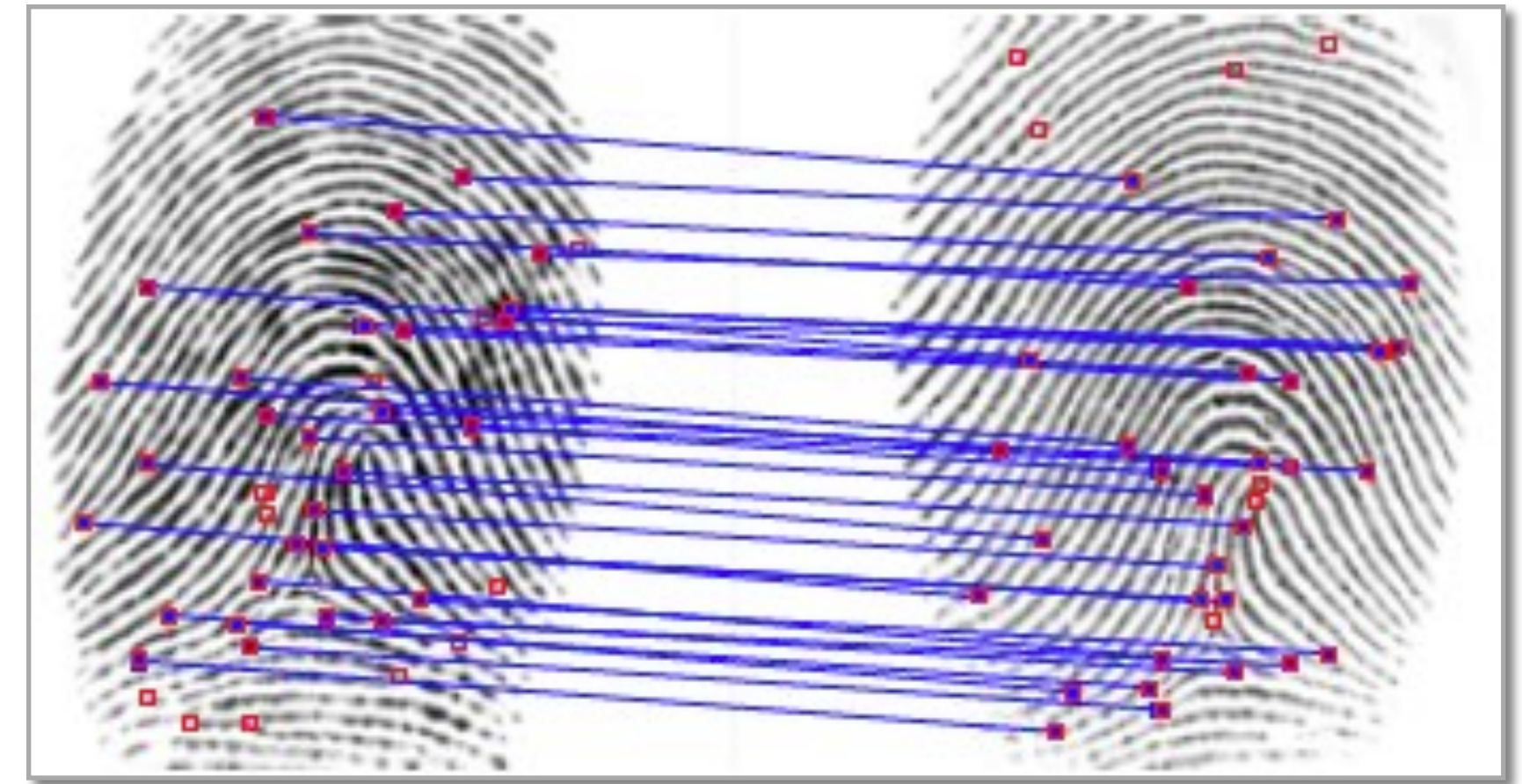
# Fingerprint Recognition



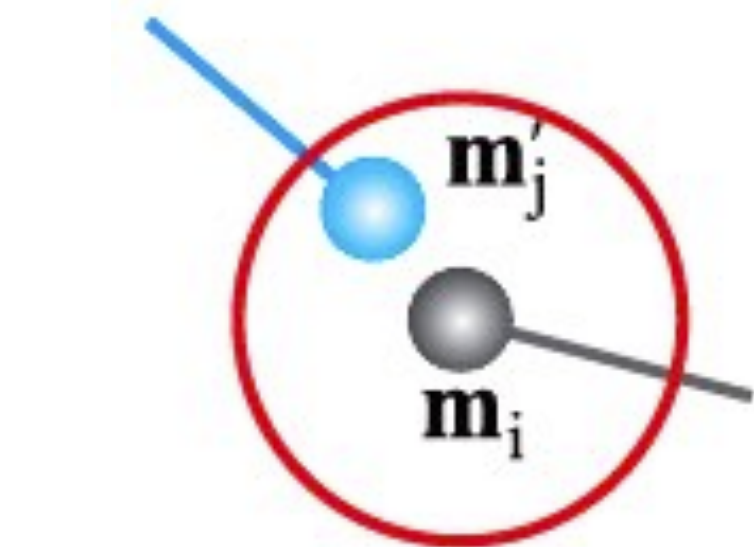
# Feature Matching

How to establish pairs of corresponding minutiae between two samples?

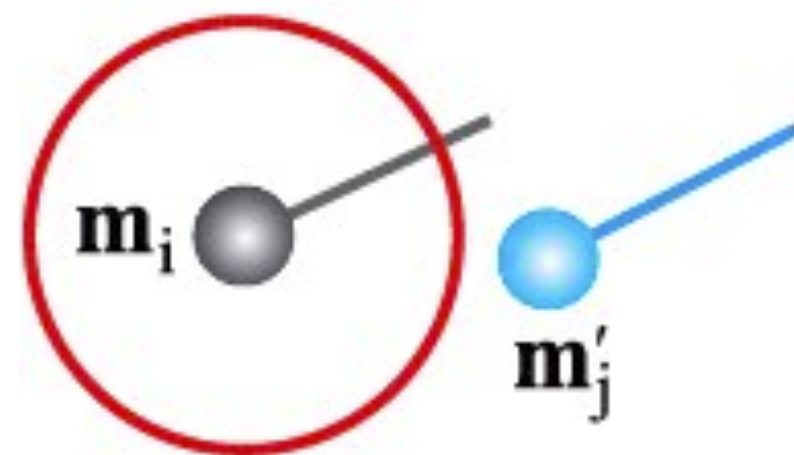
Check for agreements between both  $(x, y)$  **positions** and  $\theta$  **angles**.



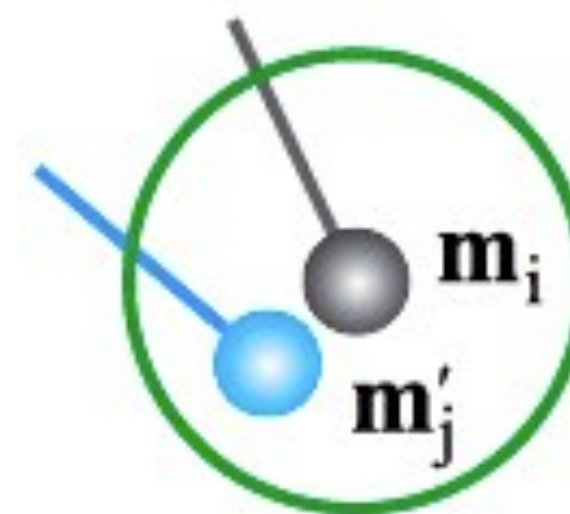
Jain, Ross, and Nadakumar  
*Introduction to Biometrics*  
Springer Books, 2011



✗ Positions agree,  
but angles do not.



✗ Angles agree, but  
positions do not.



✓ Both angles and  
positions agree.

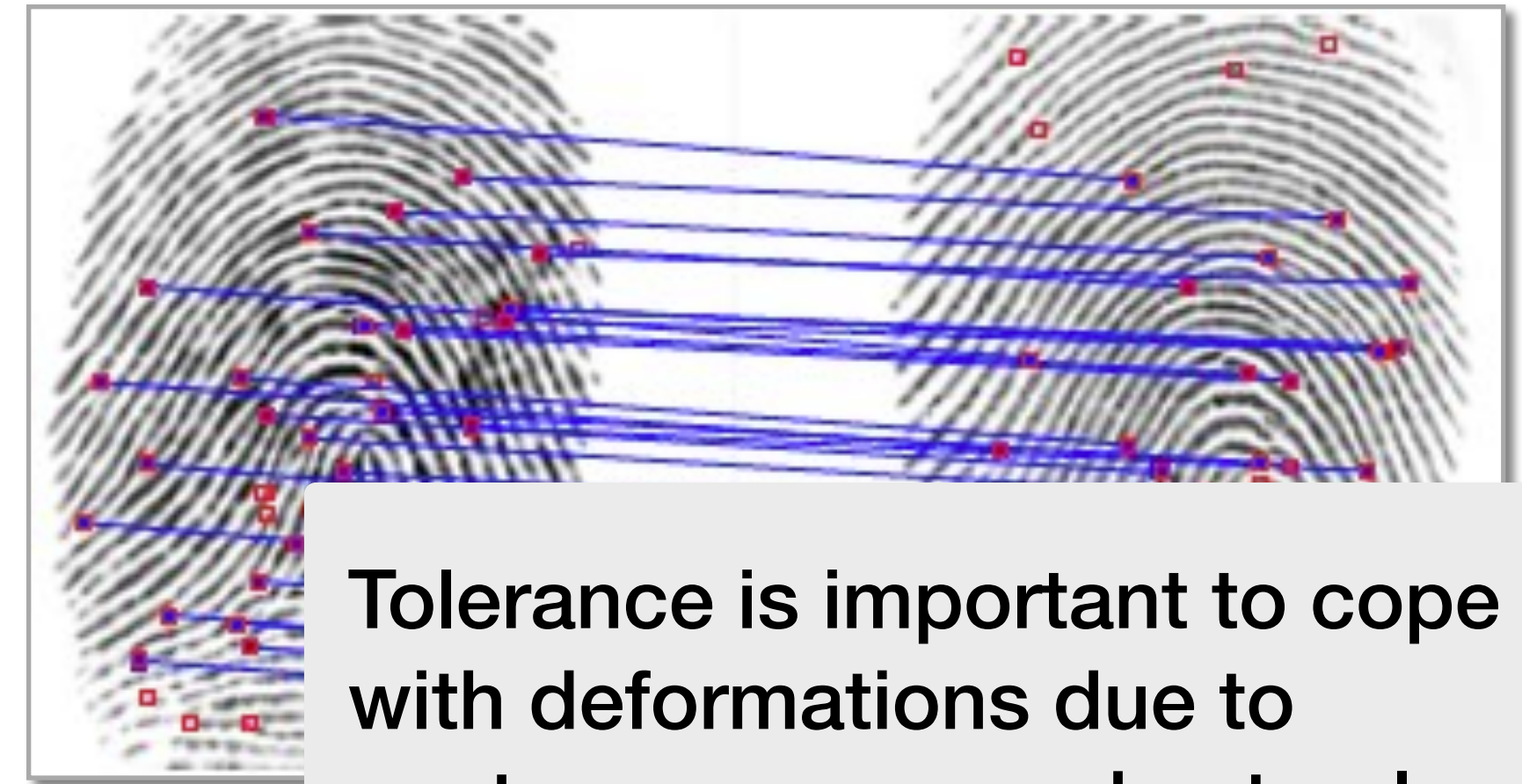
$m_i$  :  $i$ -th minutiae from image  $i$ .  
 $m'_j$  :  $j$ -th minutiae from image  $j$ .  
Source: Dr. Adam Czajka



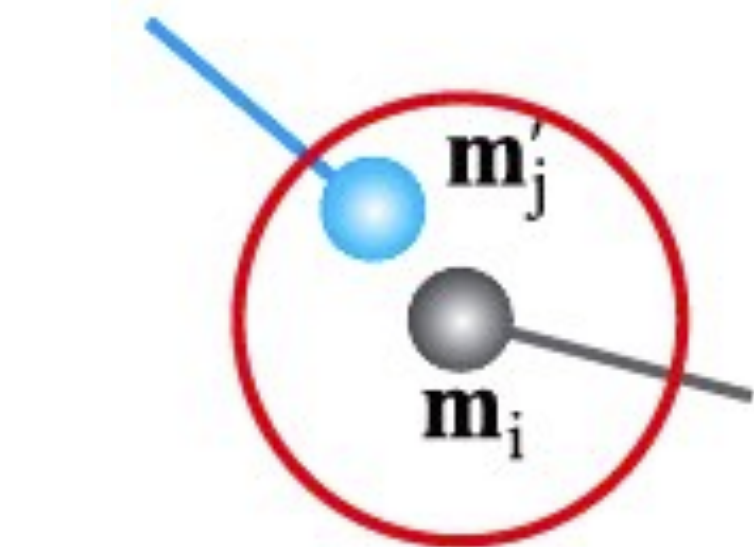
# Feature Matching

How to establish pairs of corresponding minutiae between two samples?

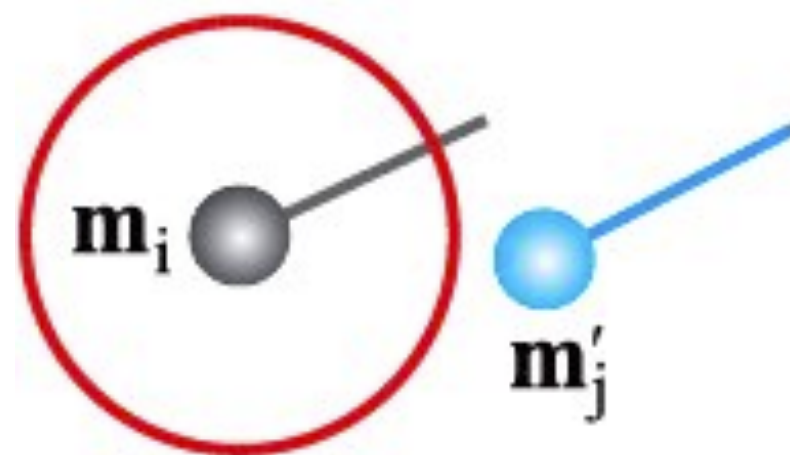
Check for agreements between both  $(x, y)$  **positions** and  $\theta$  **angles**.



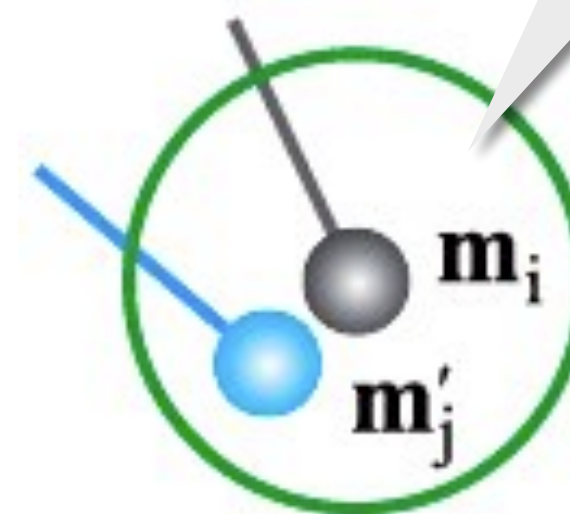
Tolerance is important to cope with deformations due to capture process and natural skin deformations.



✗ 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

# 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

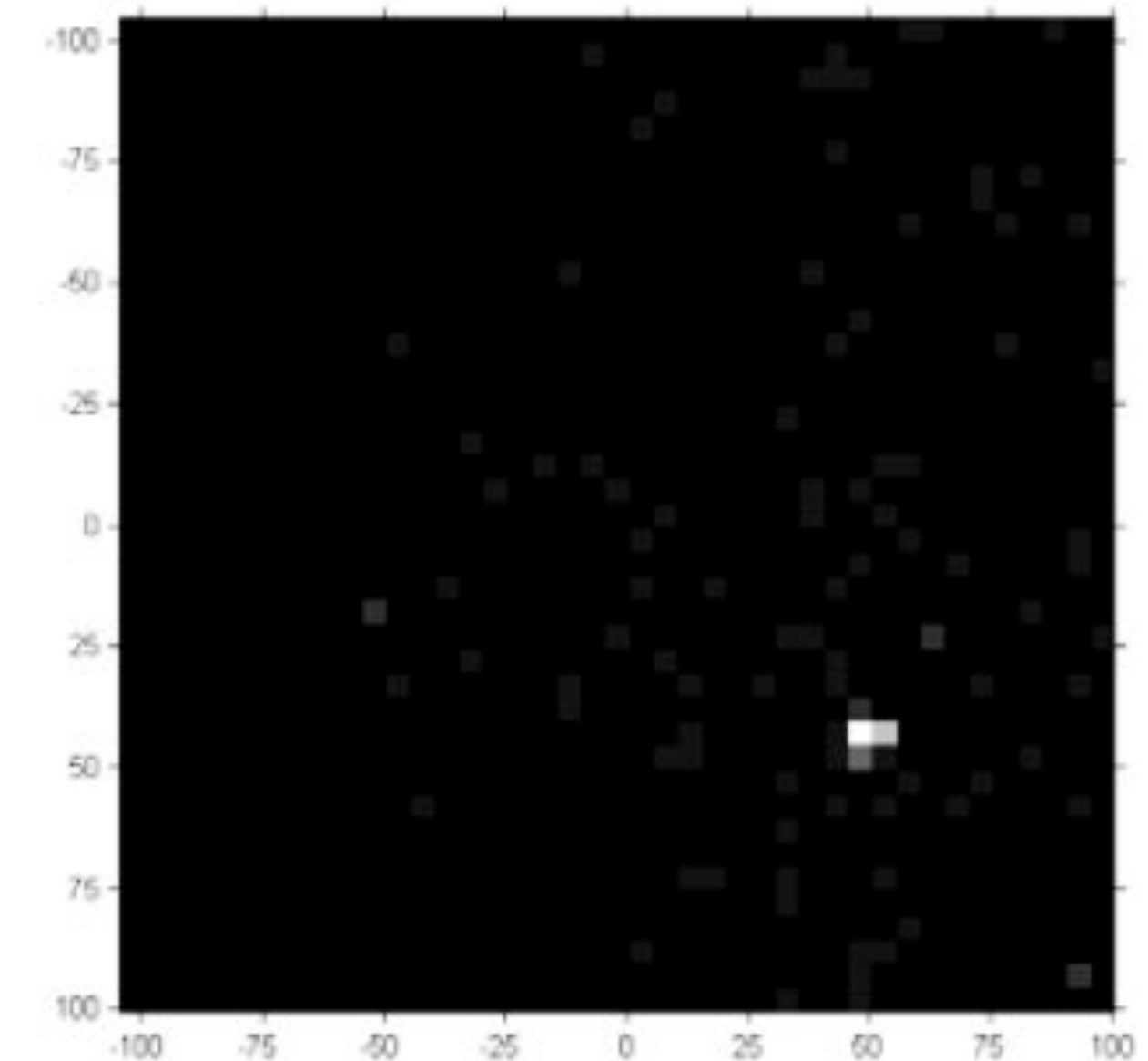


# Feature Matching

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).

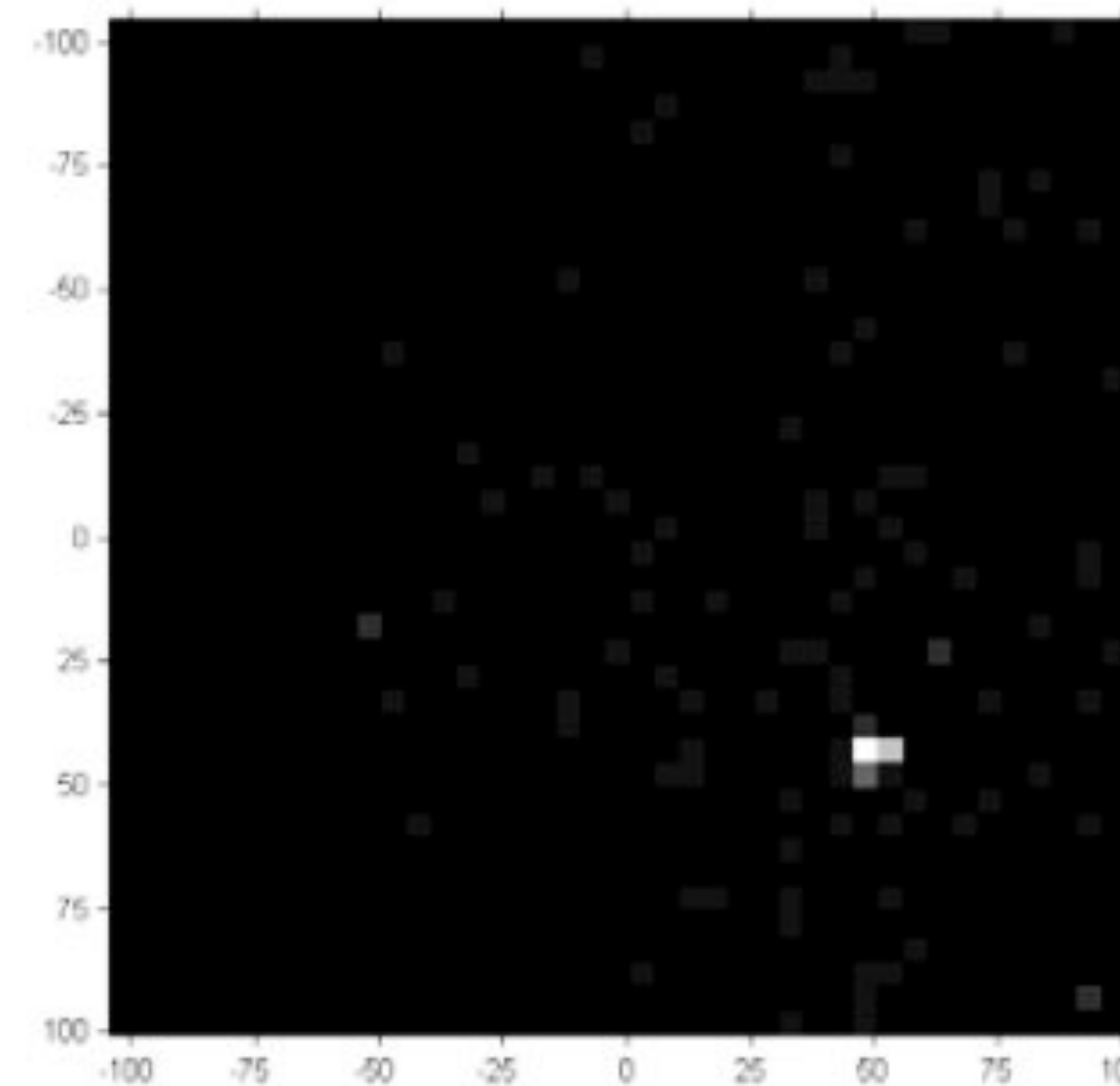
# Feature Matching

## Hough Transform



query

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



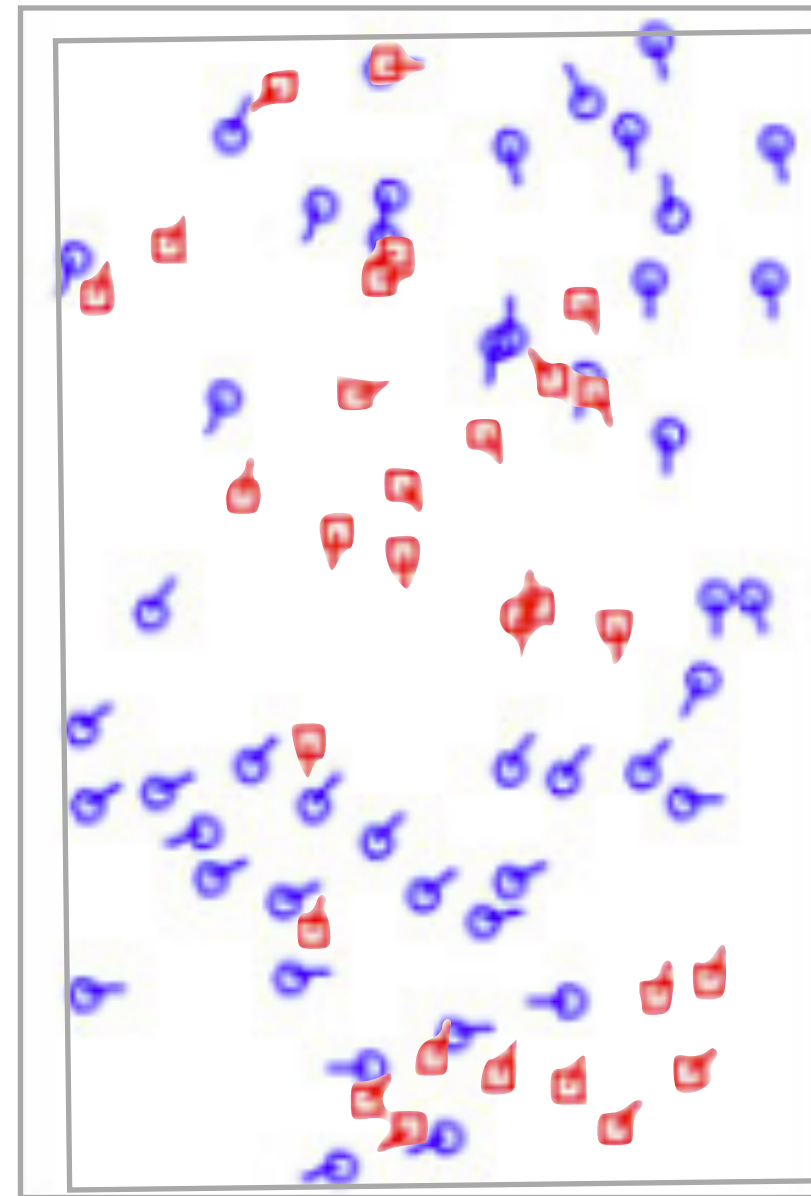
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).



# Feature Matching

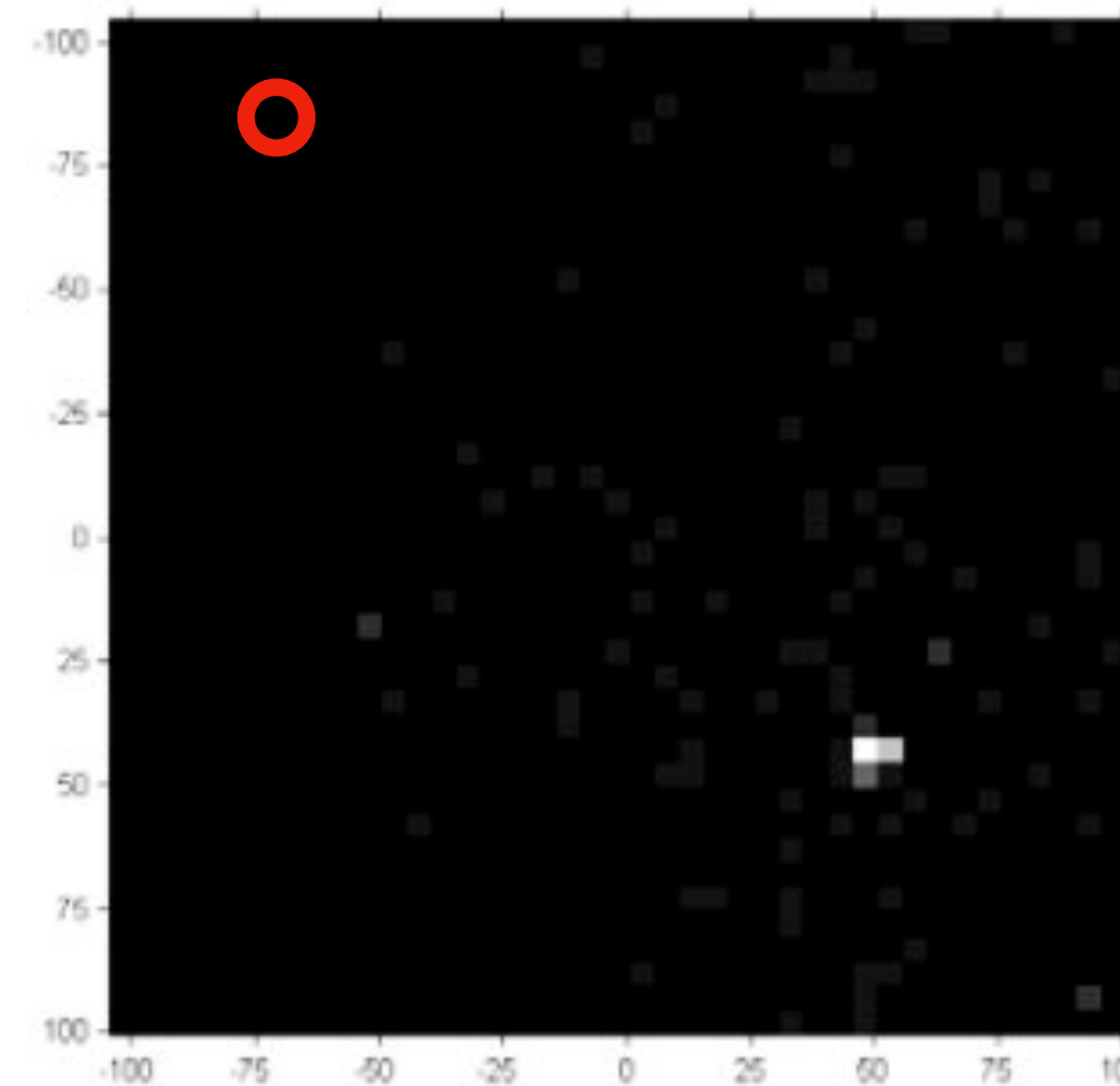
## Hough Transform

template



query

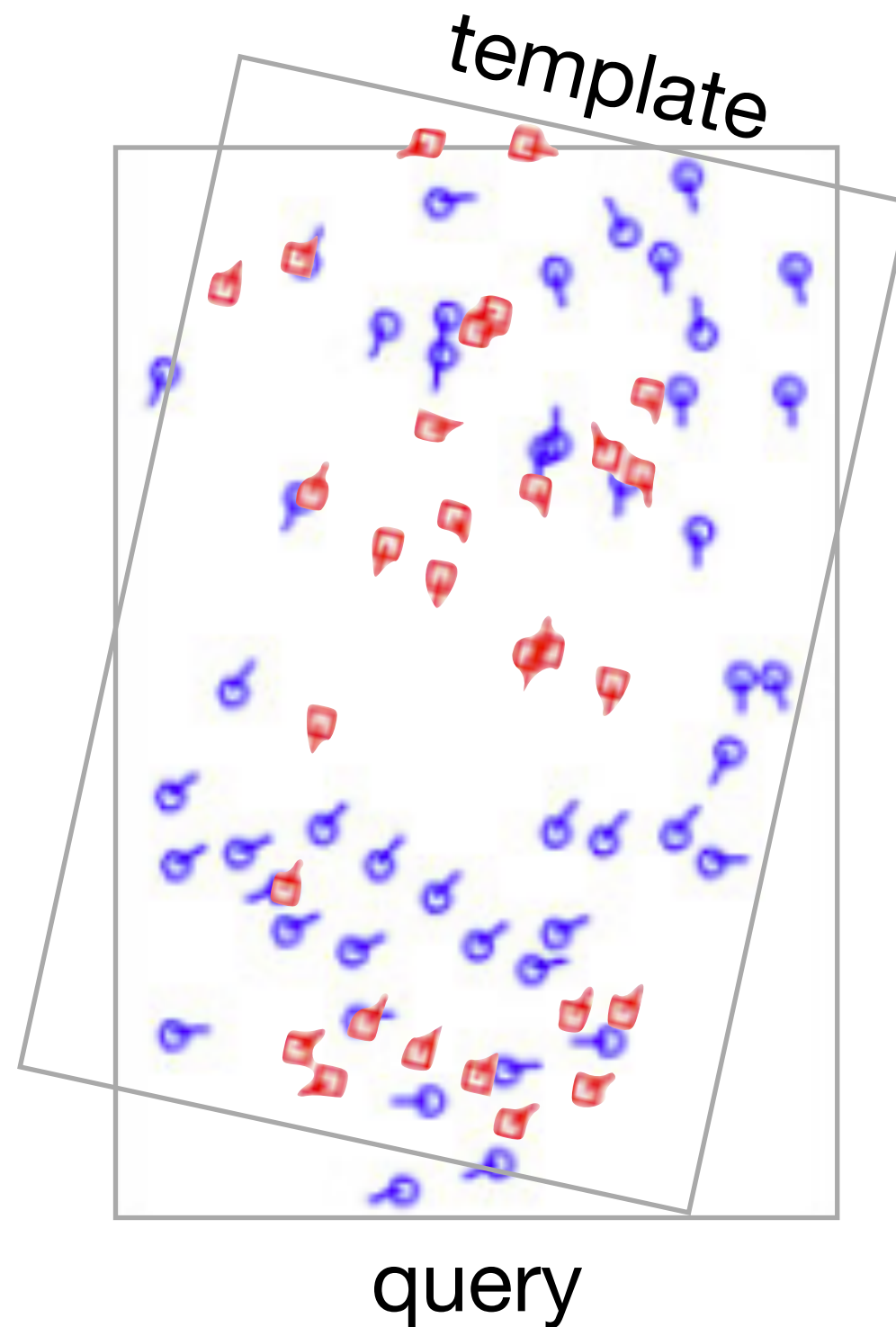
Jain, Ross, and Nadakumar  
*Introduction to Biometrics*  
Springer Books, 2011



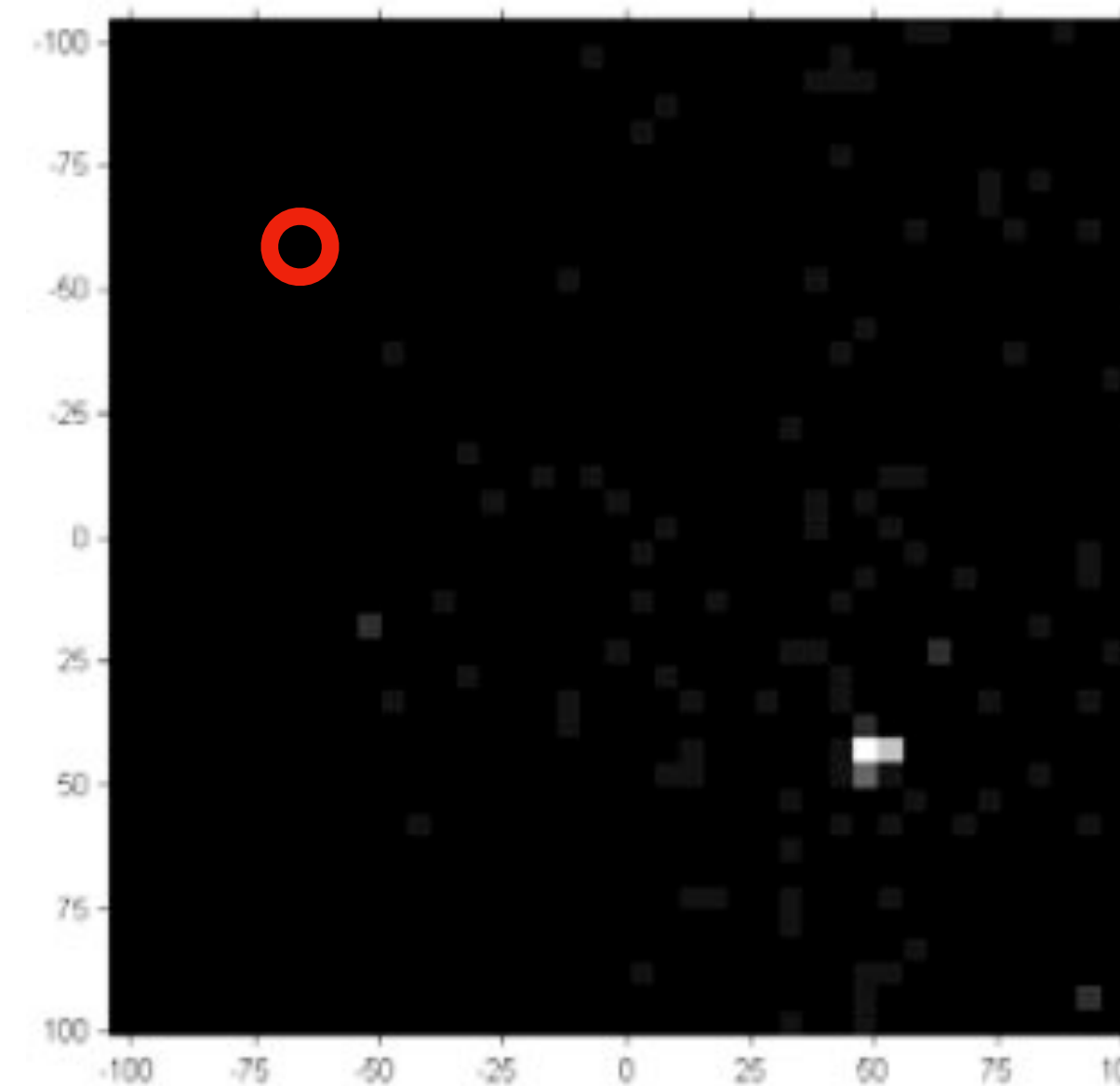
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

# Feature Matching

## Hough Transform



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

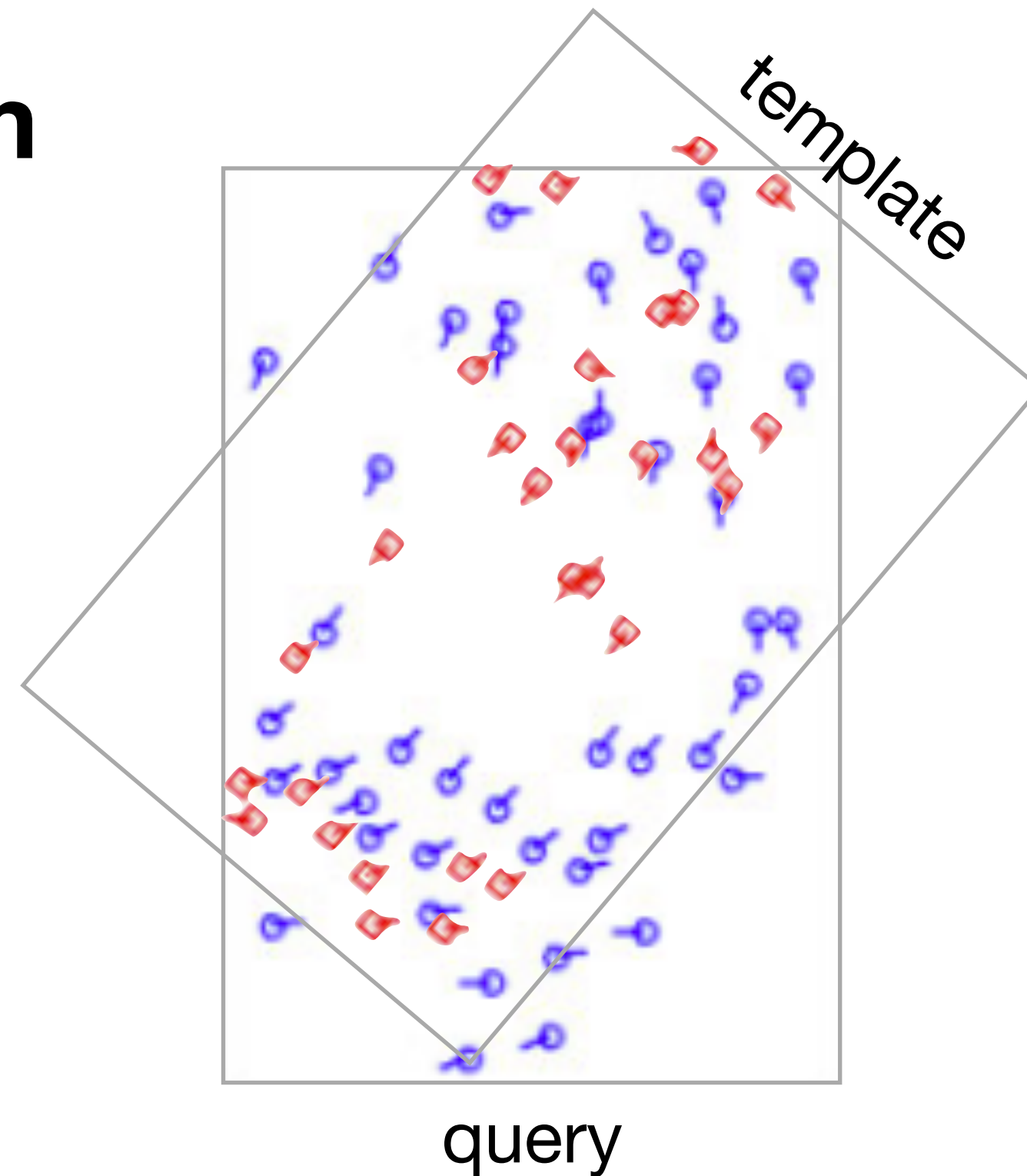


Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

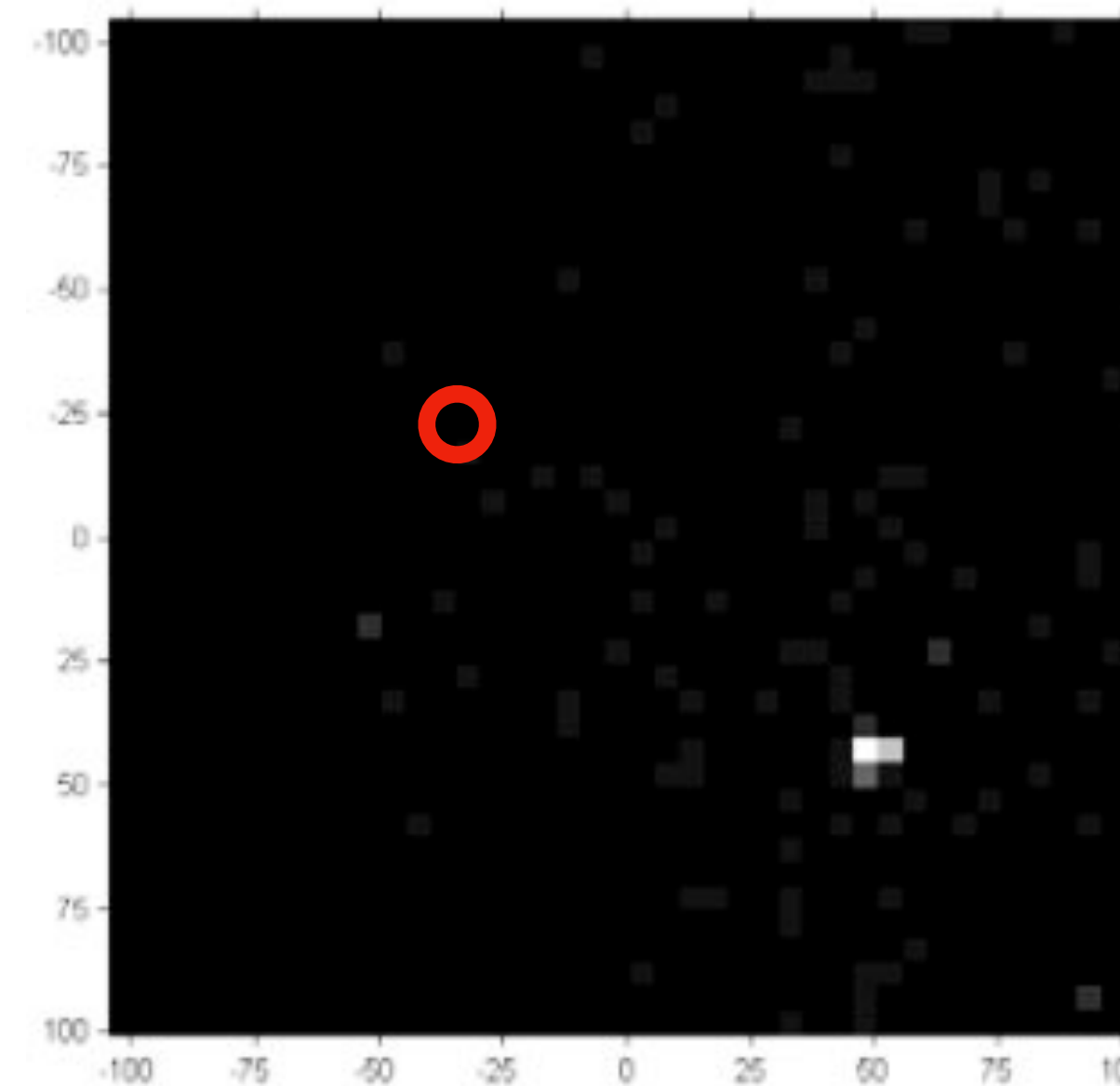


# Feature Matching

## Hough Transform



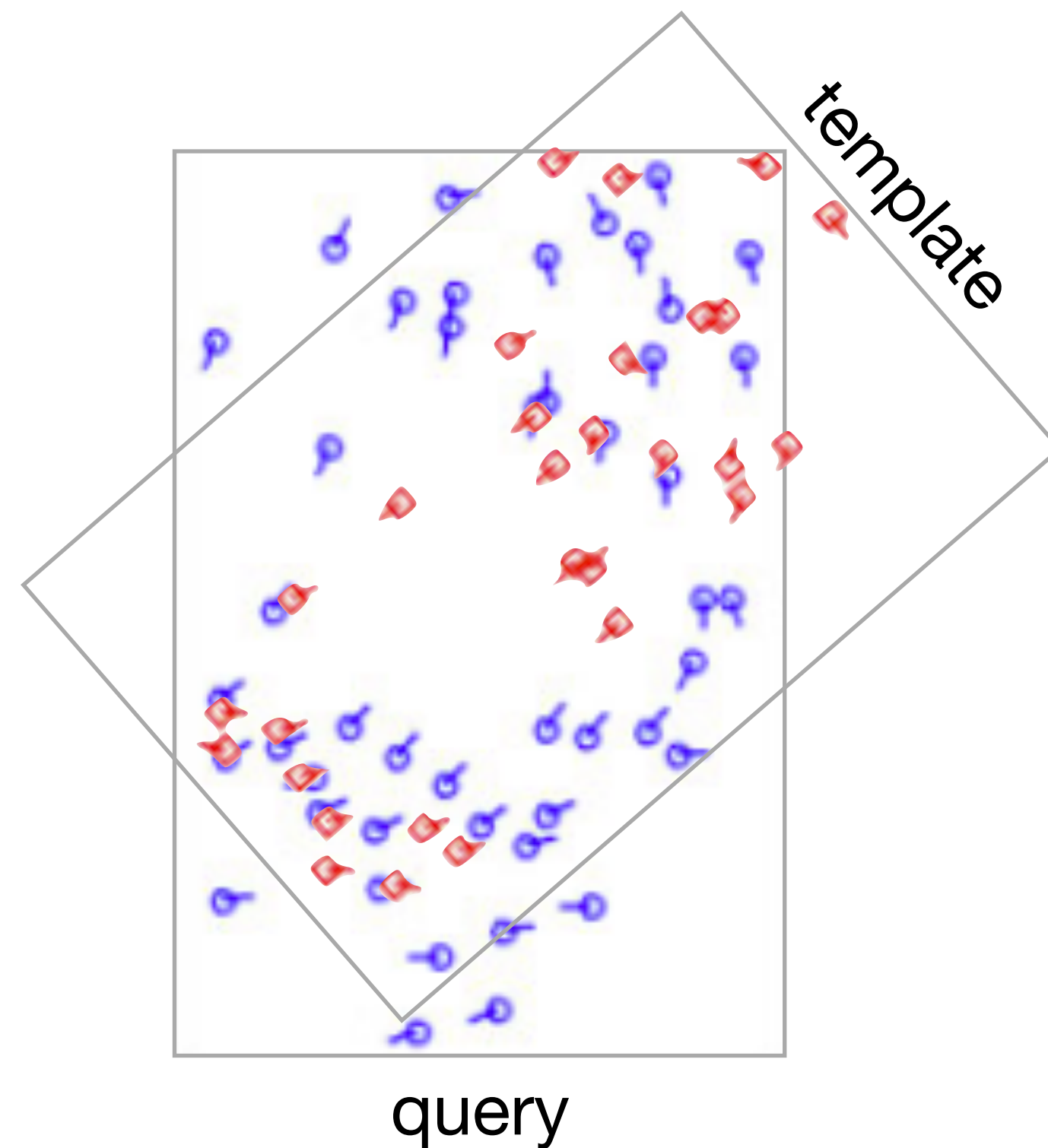
Jain, Ross, and Nadakumar  
*Introduction to Biometrics*  
Springer Books, 2011



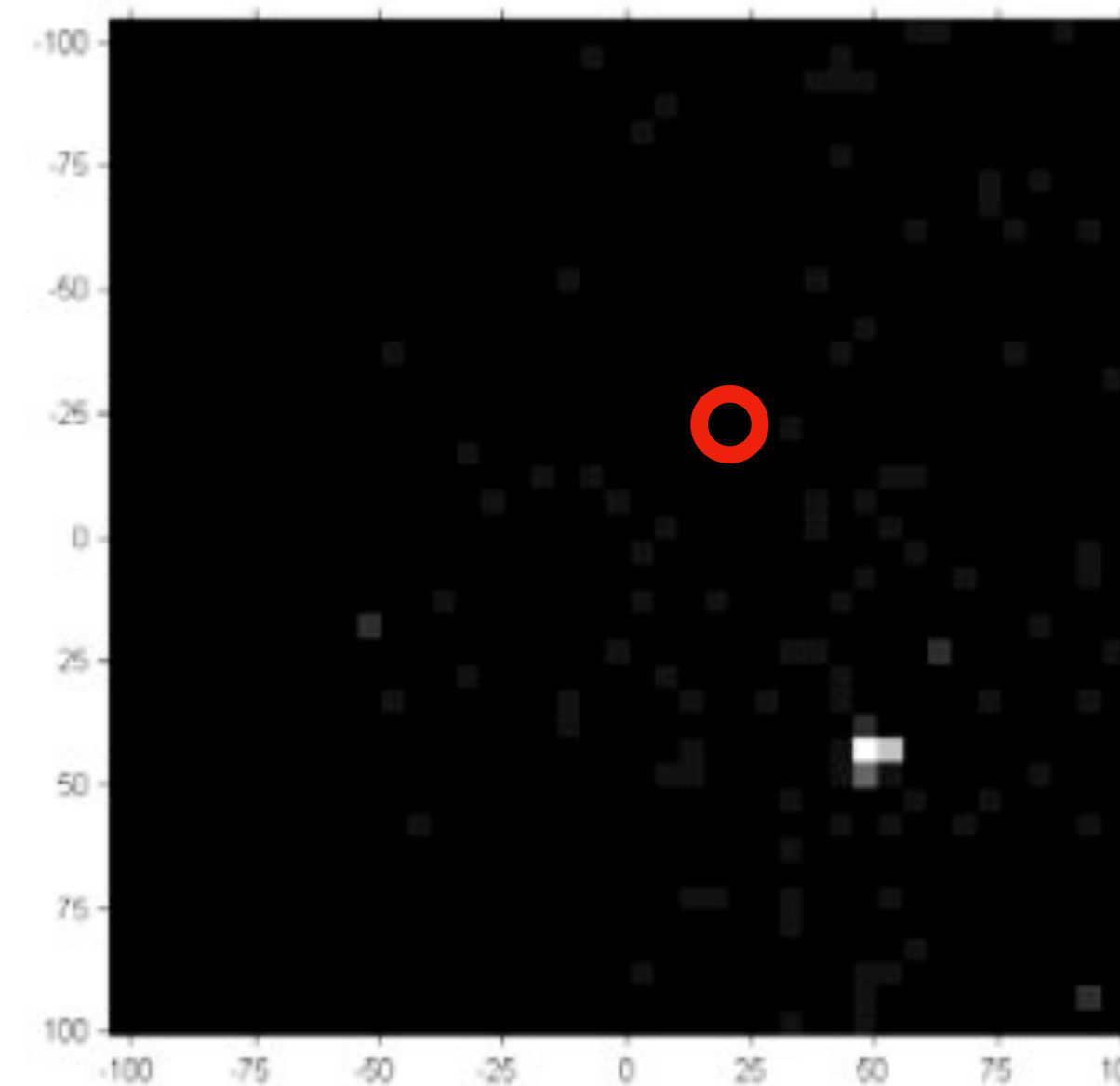
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

# Feature Matching

## Hough Transform



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

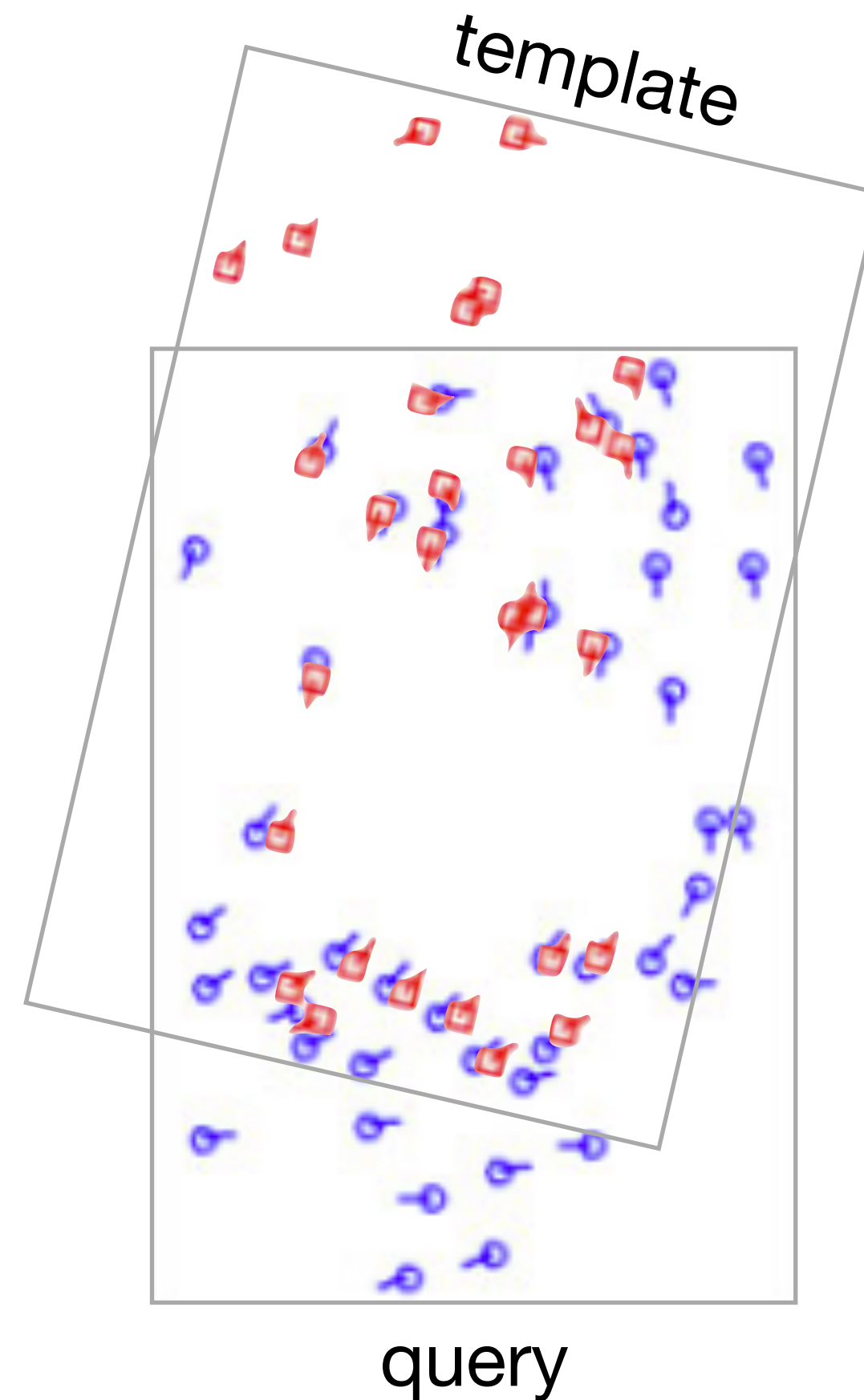


Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

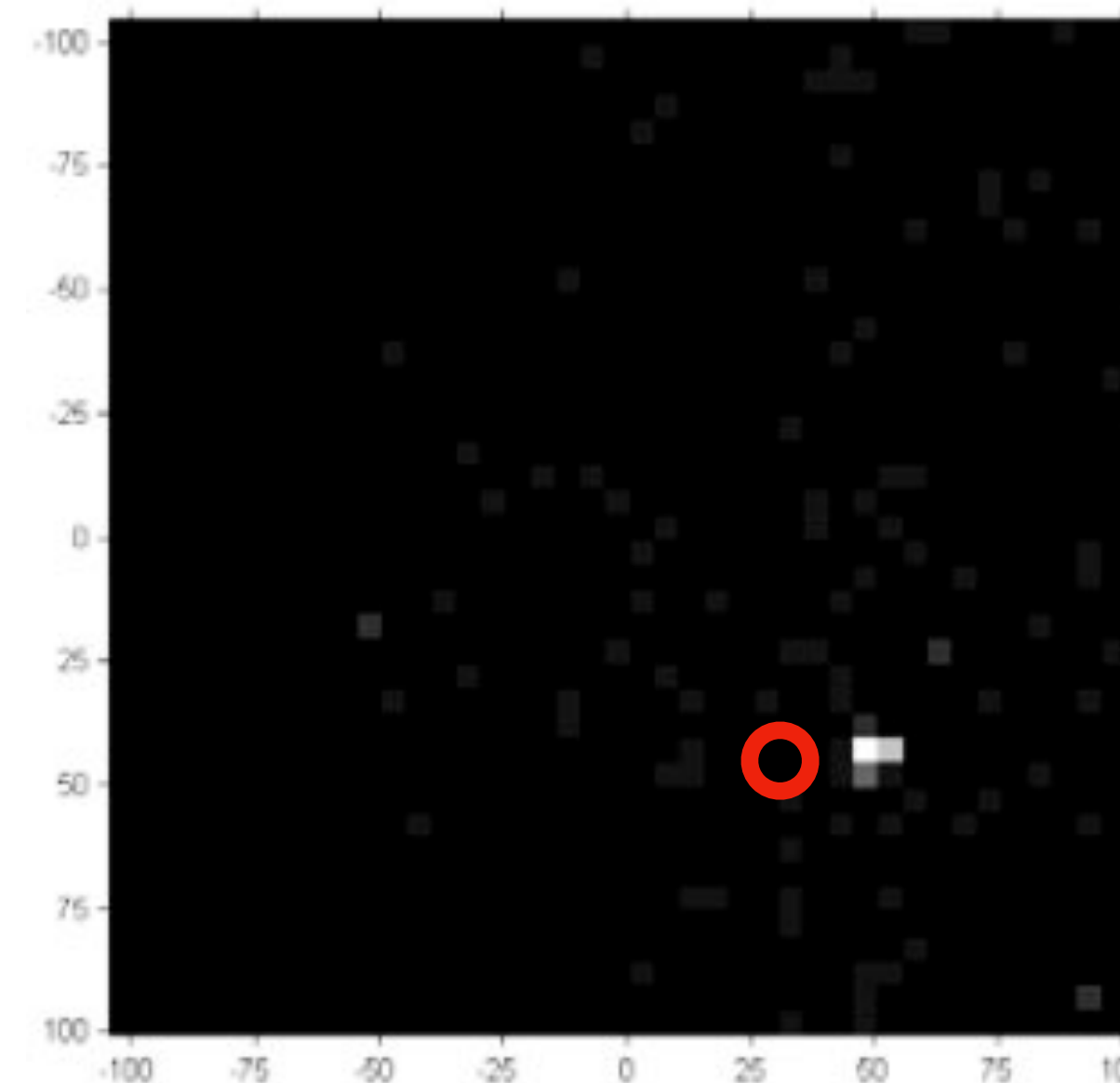


# Feature Matching

## Hough Transform



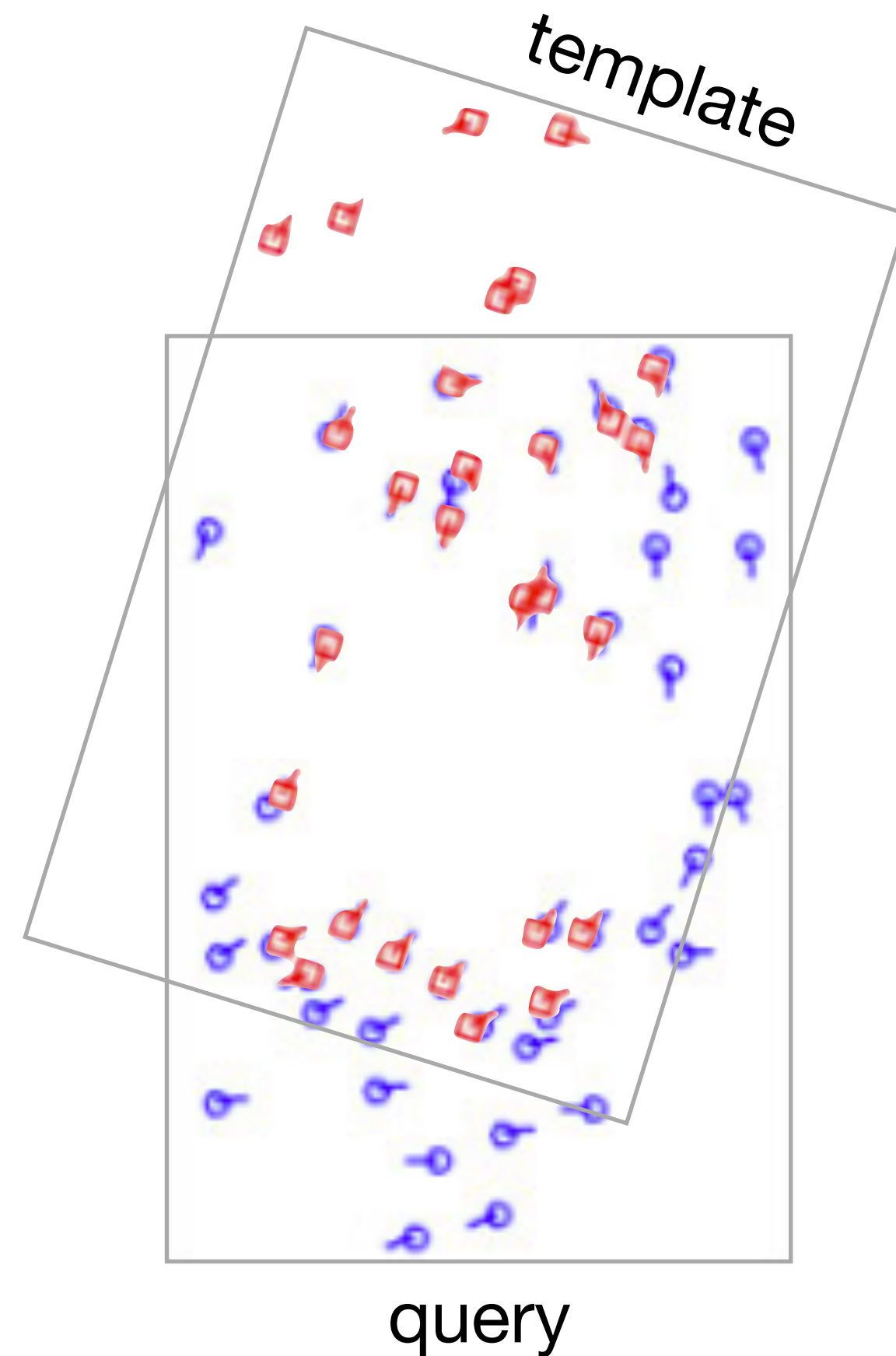
Jain, Ross, and Nadakumar  
*Introduction to Biometrics*  
Springer Books, 2011



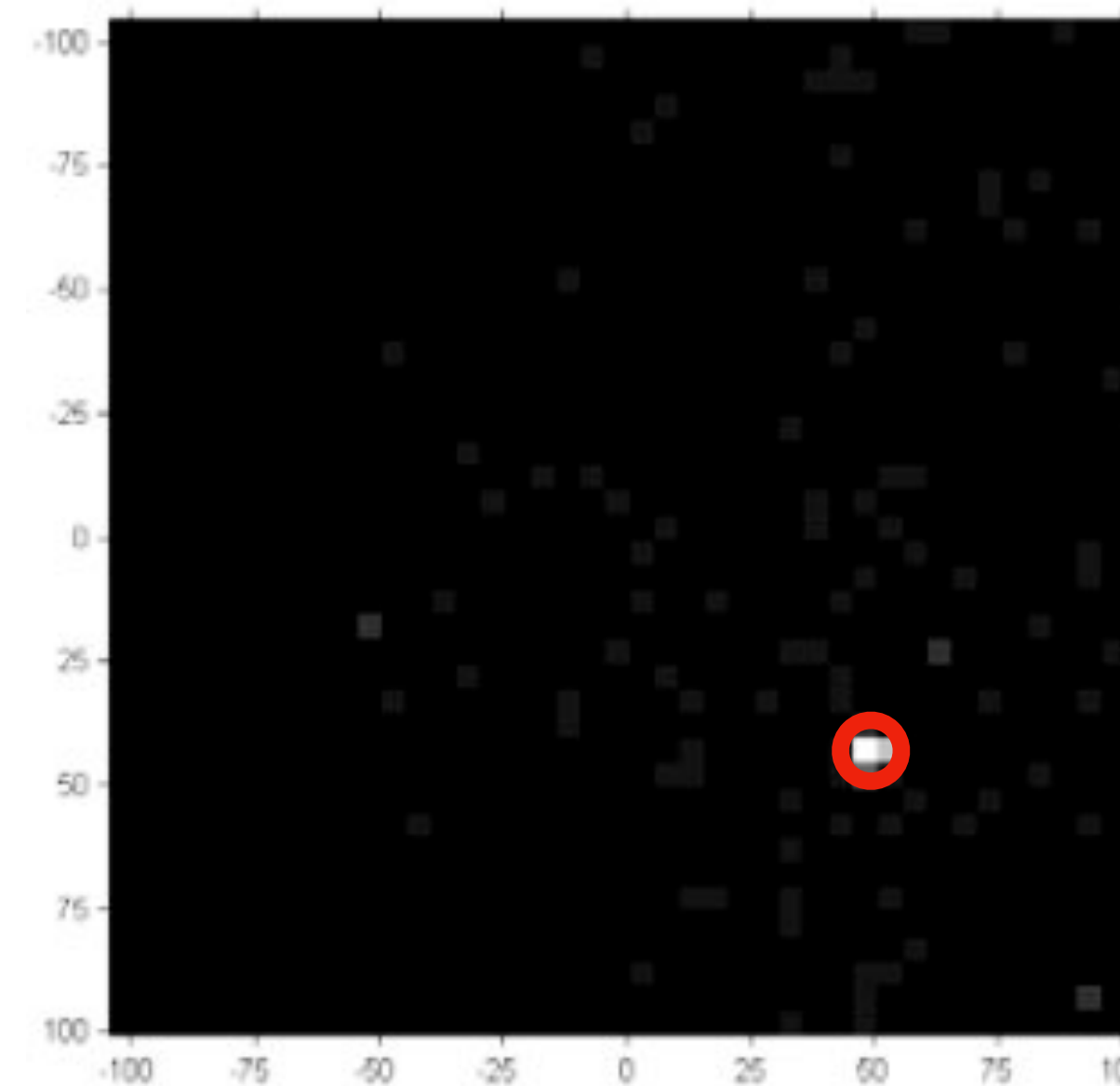
Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

# Feature Matching

## Hough Transform



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

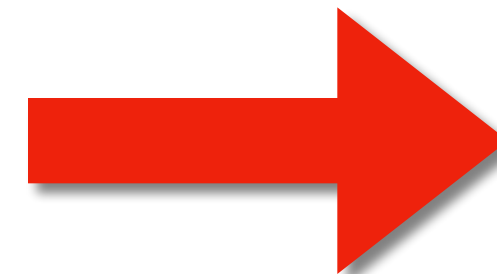
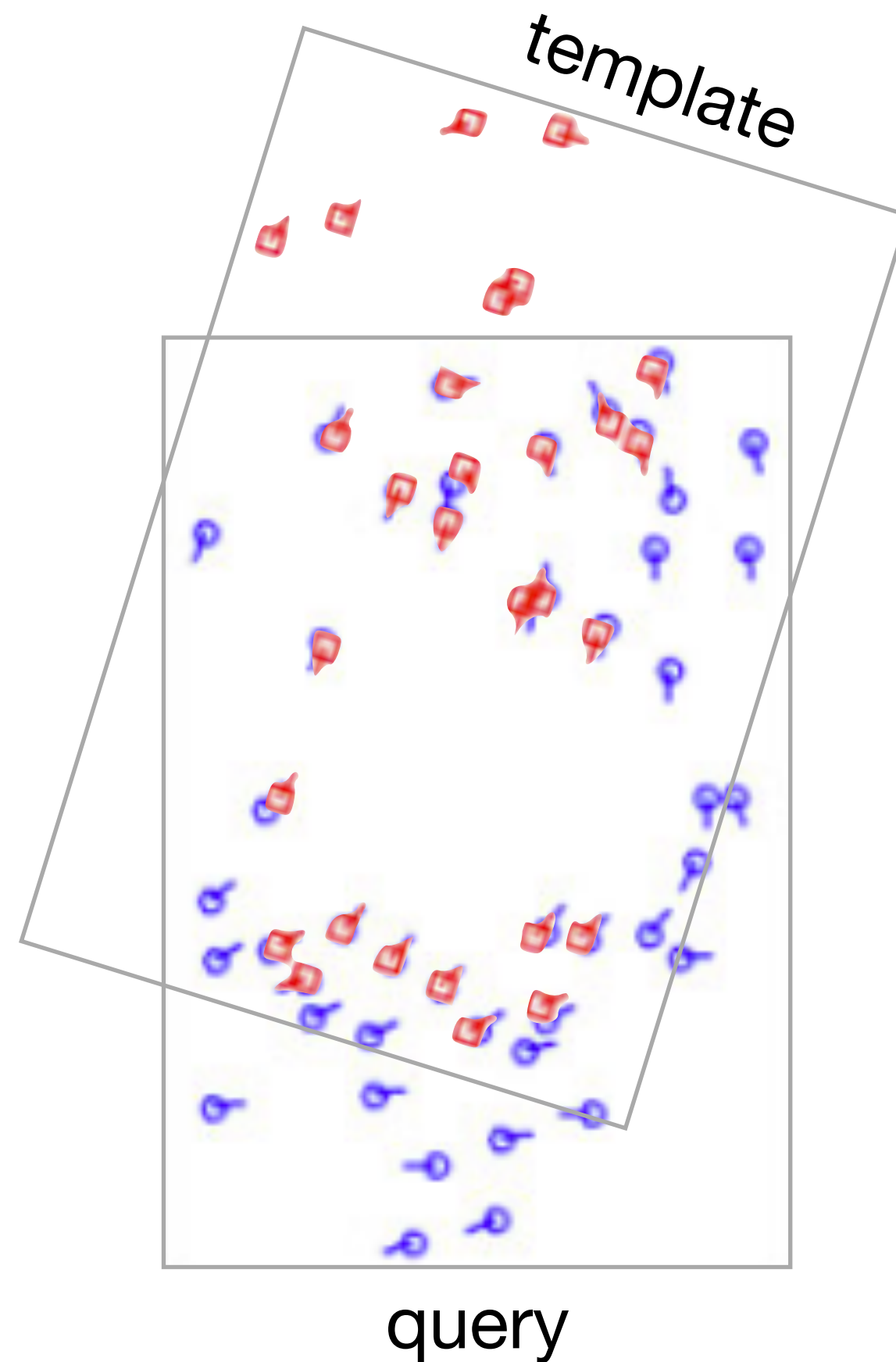


Hough-space 2D simplification with the number of matches expressed as gray scale (the more the matches, the whiter the space).

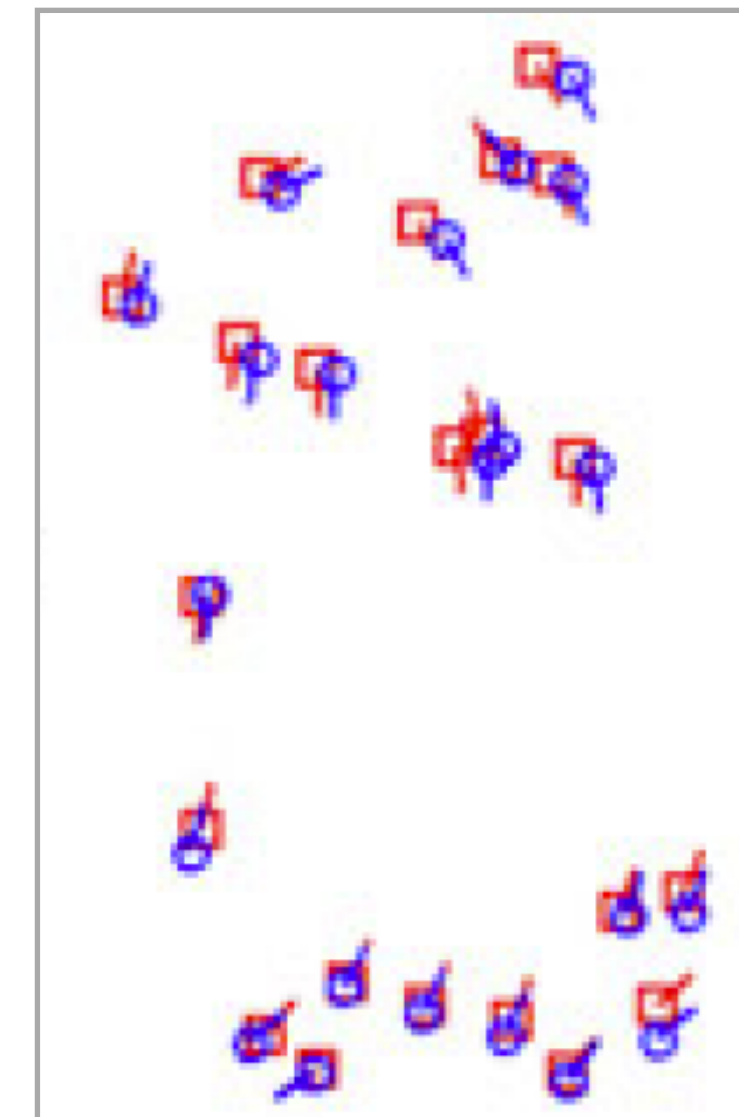


# Feature Matching

**Hough Transform**

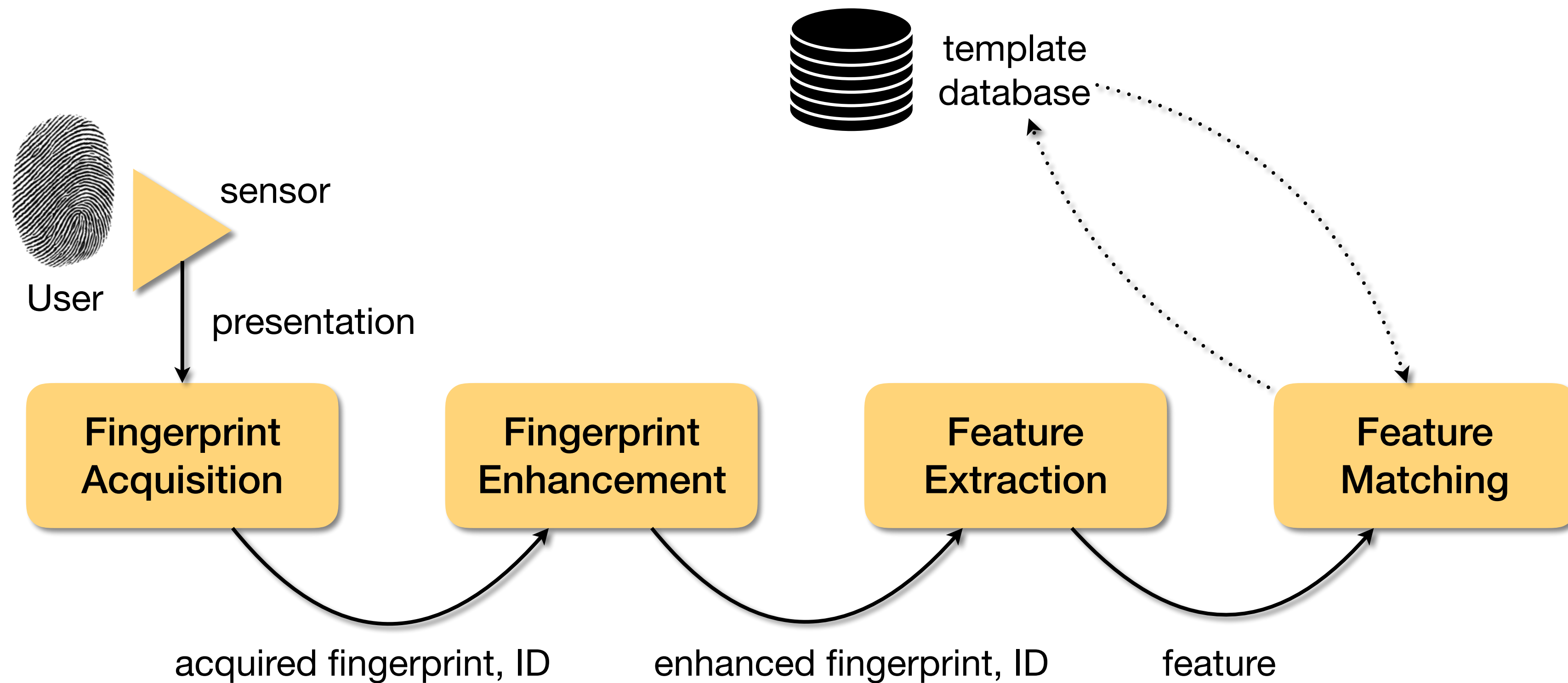


Jain, Ross, and Nadakumar  
*Introduction to Biometrics*  
Springer Books, 2011



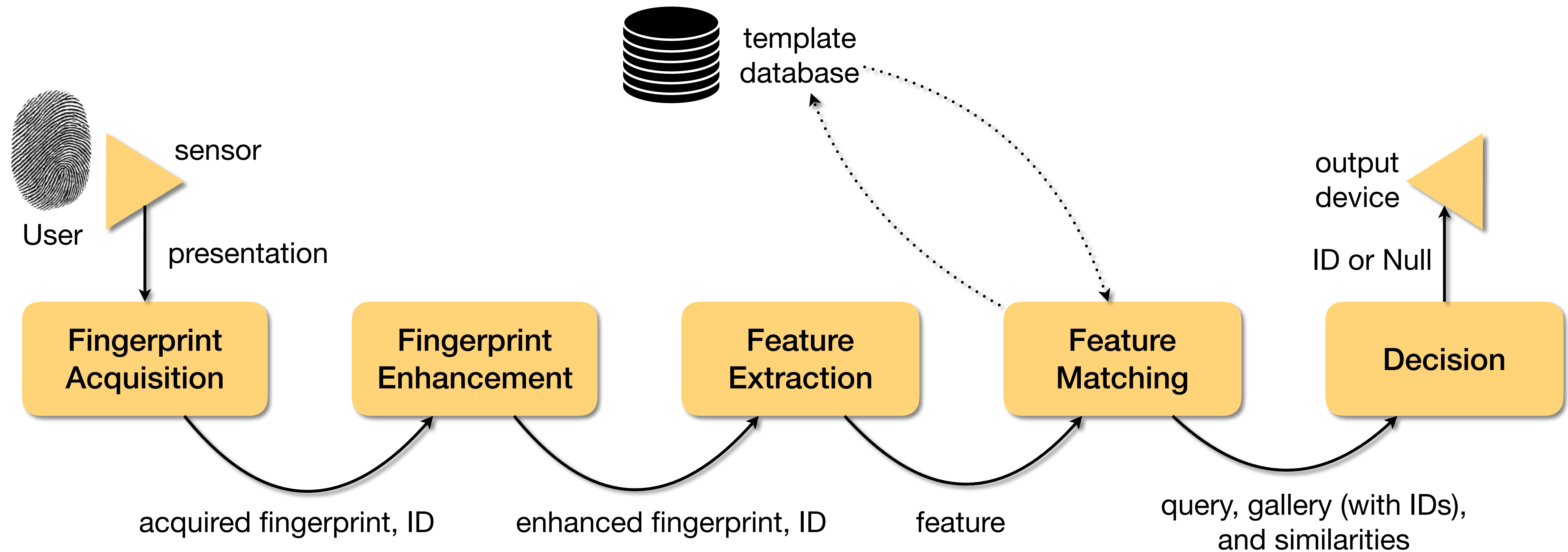
21 matches

# Fingerprint Recognition





# Fingerprint Recognition



# Decision

## Similarity-based Decision

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

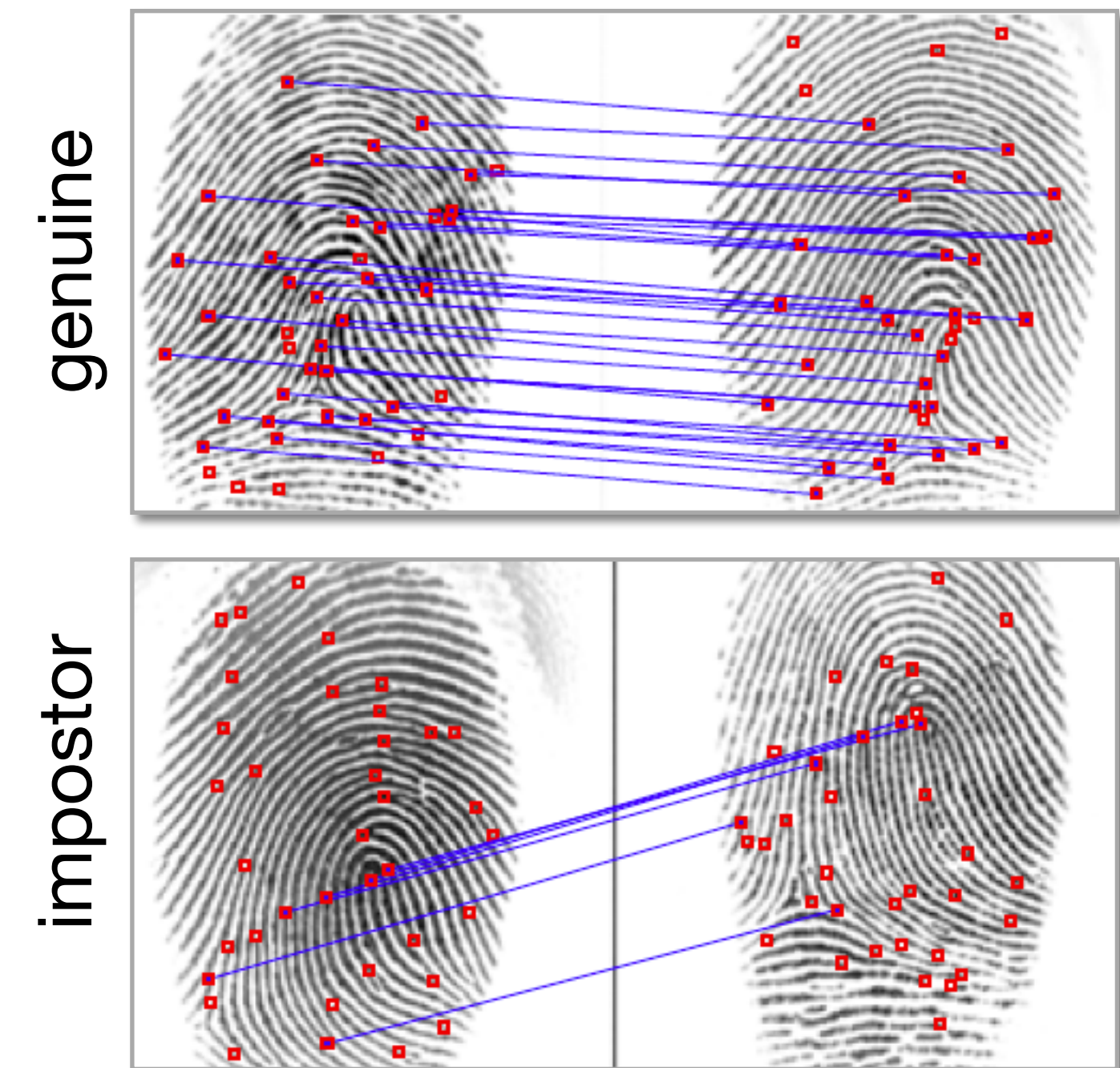
### Simple score

Let  $M$  be the number of minutiae in image  $i$ .

Let  $N$  be the number of minutiae in image  $j$ .

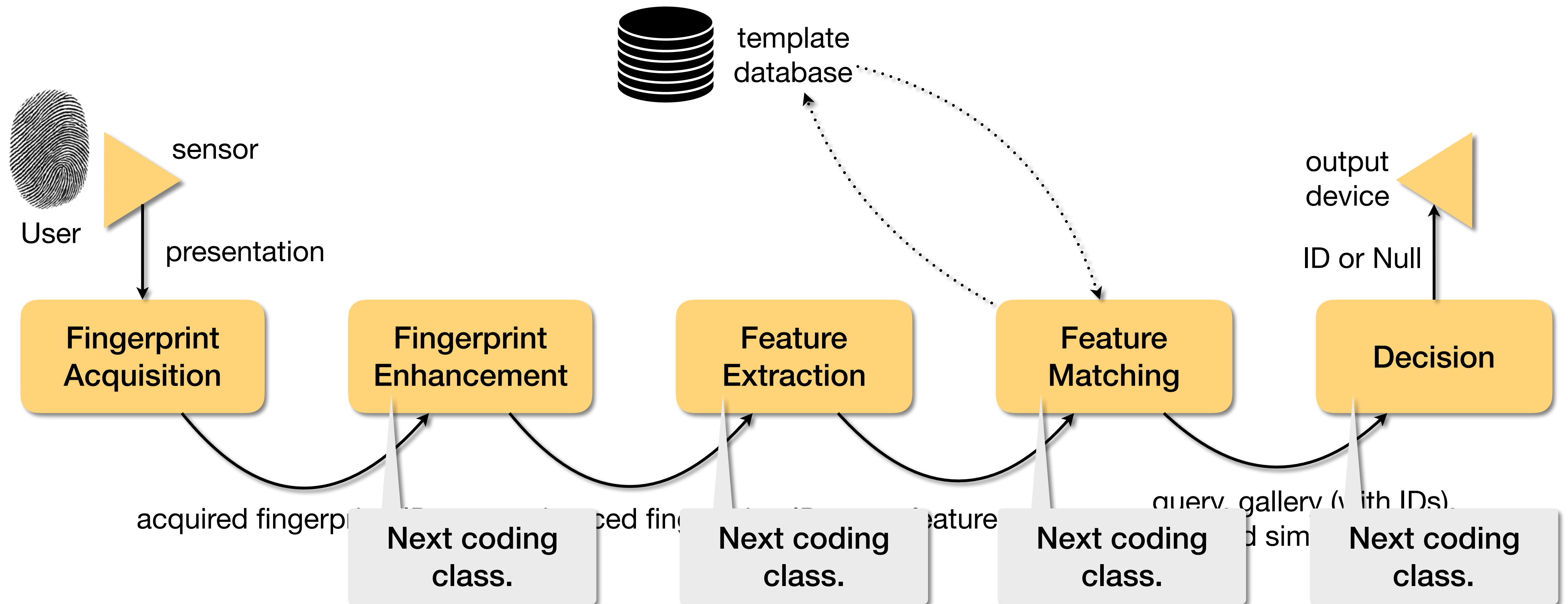
$$sim\_score = \frac{\#matches}{(M + N)/2}$$

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





# Fingerprint Recognition



# S'up Next?

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





## **Acknowledgments**

This material is heavily based on  
Dr. Adam Czajka's and Dr. Walter Scheirer's courses.  
Thank you, professors, for kindly allowing me to use your material.

<https://engineering.nd.edu/profiles/aczajka>  
<https://www.wjscheirer.com/>