

# Fingerprint Recognition I

CSE 40537/60537 Biometrics

**Daniel Moreira**  
Spring 2020

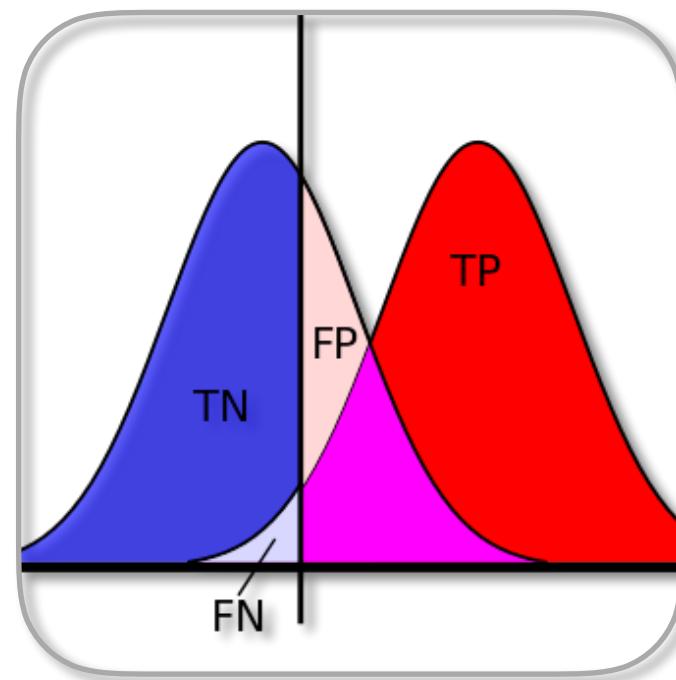


# Today you will...

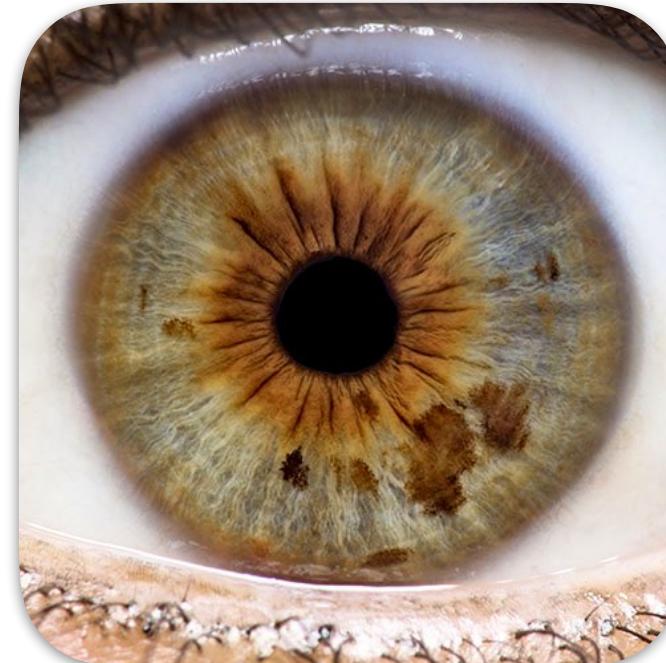
*Get to know*  
The history of the usage of fingerprints.  
Useful fingerprint features.

# Course Overview

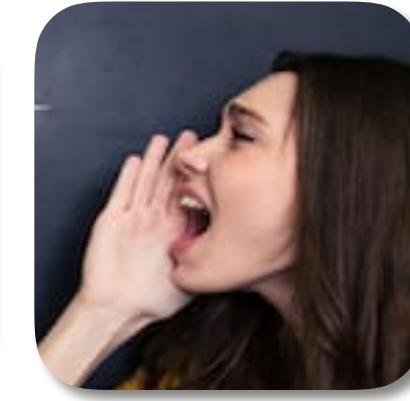
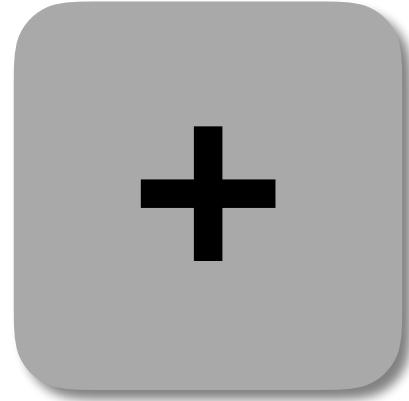
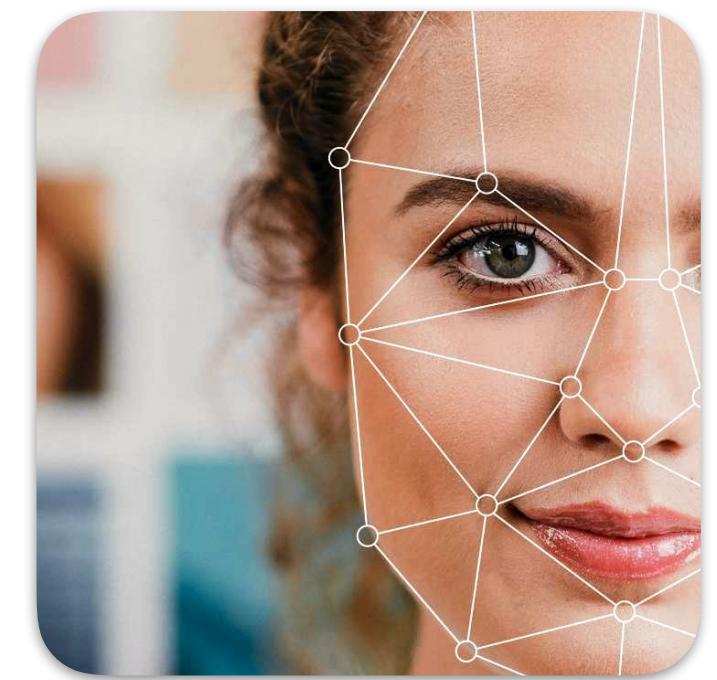
## Content



**Basics**  
Concepts  
Metrics  
Metric implementation



**Core Traits (3)**  
Concepts  
Baseline implementation  
Data collection  
Evaluation  
Attacks  
Assignments



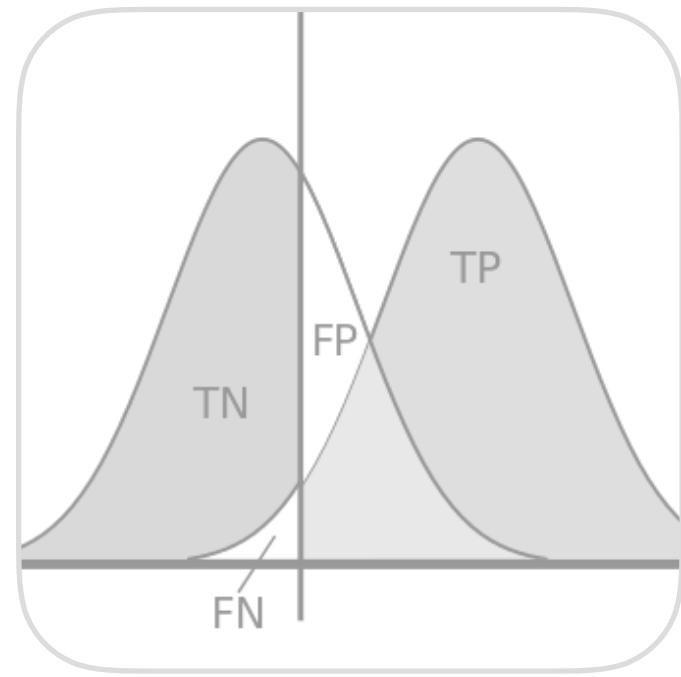
**Alternative Traits and Fusion Concepts**



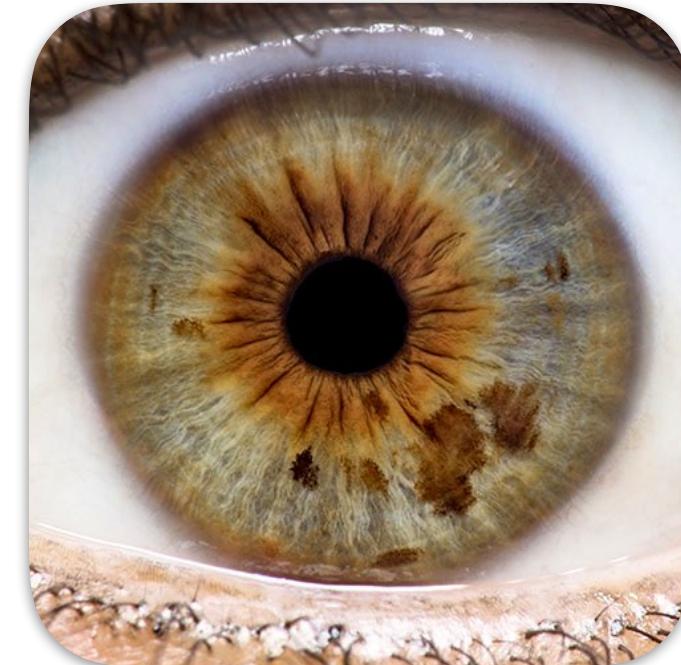
**Invited Talks (2)**  
State of the art  
Future work

# Course Overview

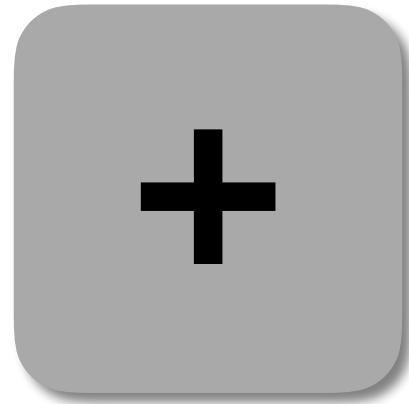
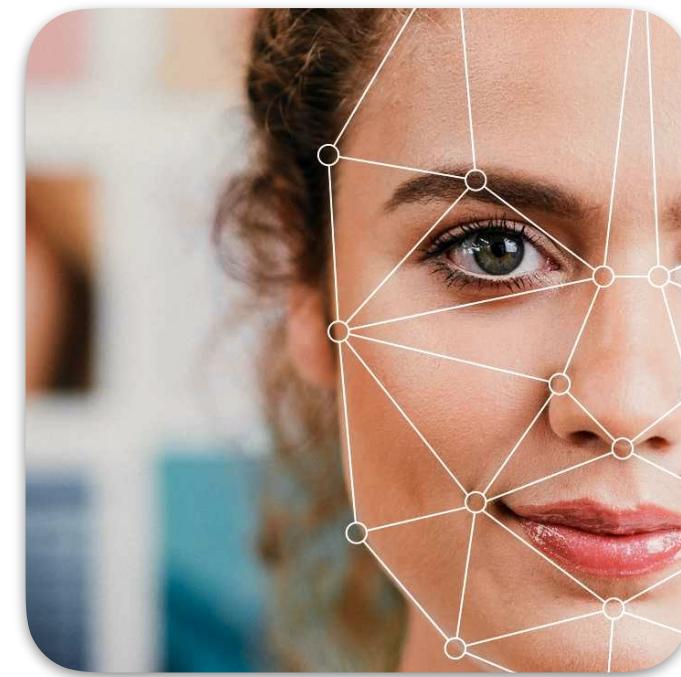
## Content



Basics  
Concepts  
Metrics  
Metric implementation



**Core Traits (3)**  
Concepts  
Baseline implementation  
Data collection  
Evaluation  
Attacks  
Assignments



**Alternative Traits and Fusion Concepts**



**Invited Talks (2)**  
State of the art  
Future work

# History

**Nehemiah Grew (UK, 1684)**  
Pioneering scientist.

Described the existence of  
**ridges, valleys, and**  
**sweat pores.**



# History

**Marcello Malpighi**  
**(University of Bologna, Italy, 1686)**  
Pioneering classification of  
fingerprints.

Noticed that there were  
similar patterns across fingerprints,  
which could be used to group  
samples.



# History

## **Sir William Herschel (UK, 1858)**

Pioneering usage of fingerprints  
for identification.

Noticed the uniqueness and  
permanence of fingerprints.

Used fingerprints within contracts  
while working as an officer in the  
Indian Civil Service.

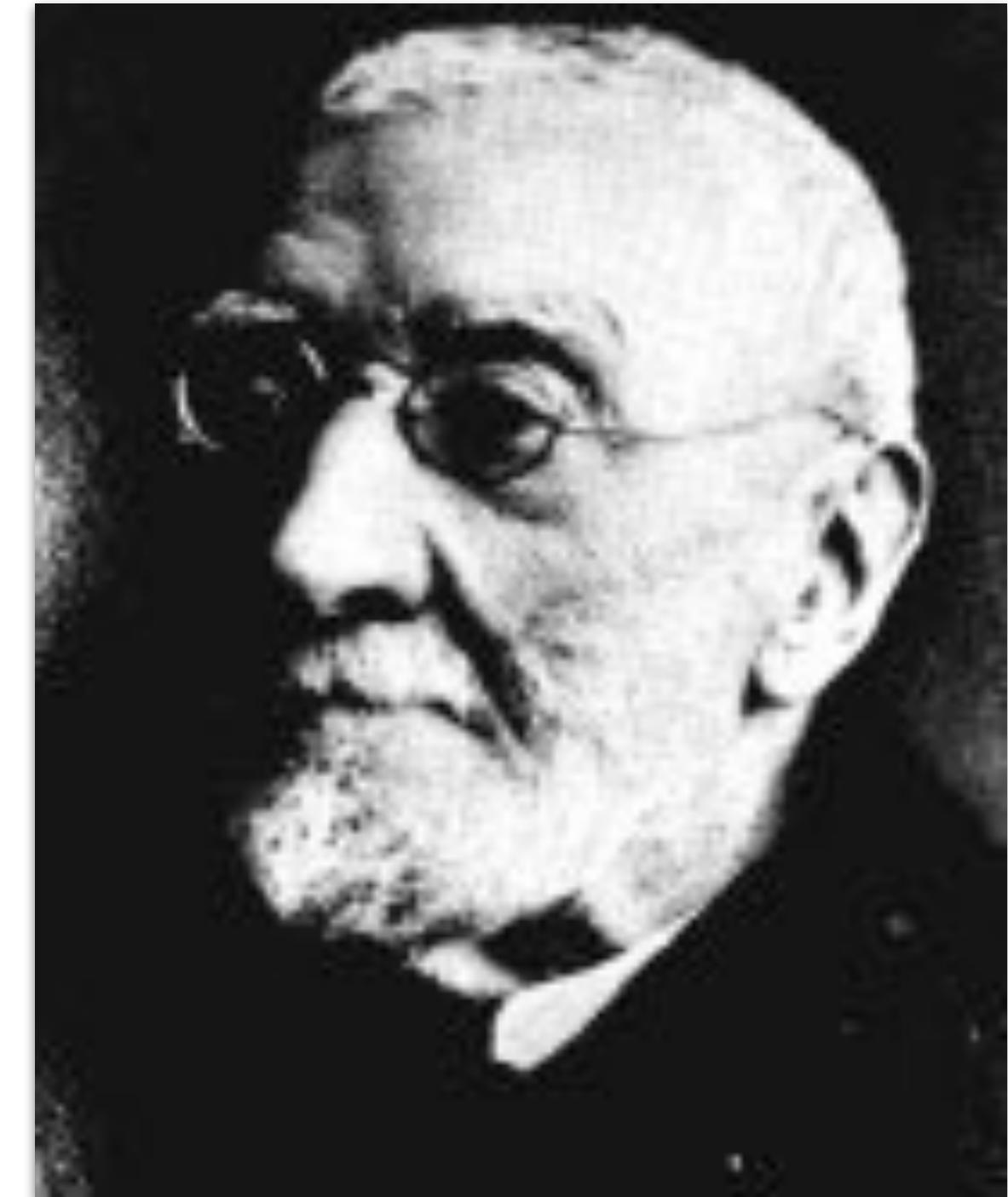


# History

## **Henry Faulds (UK, 1880)**

Pioneering usage of fingerprints  
in a forensic scenario.

Collected a latent fingerprint from a bottle  
and identified the author of a theft  
in a hospital in Tokyo.

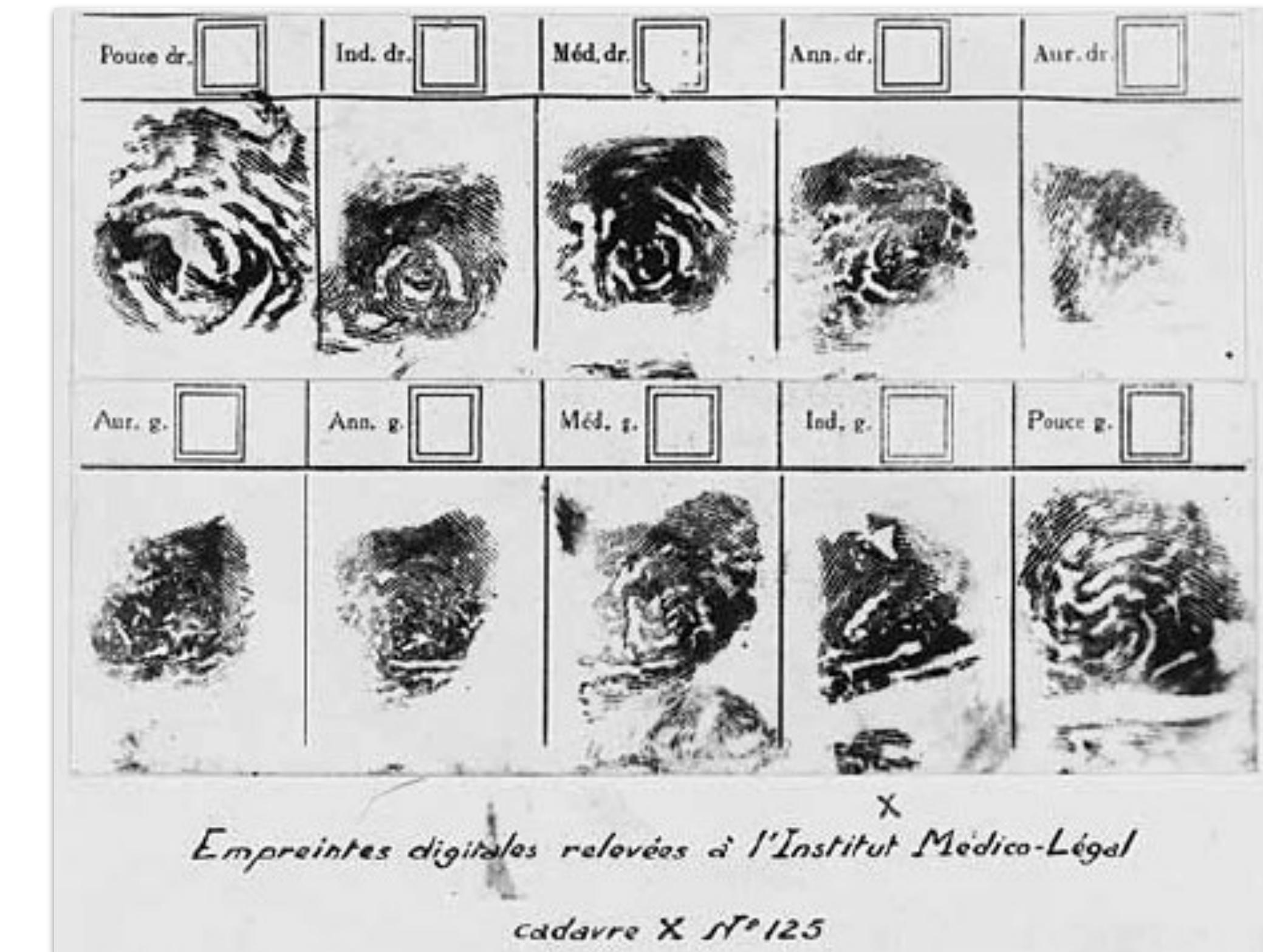


# History

**Henry Faulds (UK, 1880)**

Pioneering usage of fingerprints  
in a forensic scenario.

Performed the first experiments  
showing the uniqueness of  
fingerprints.

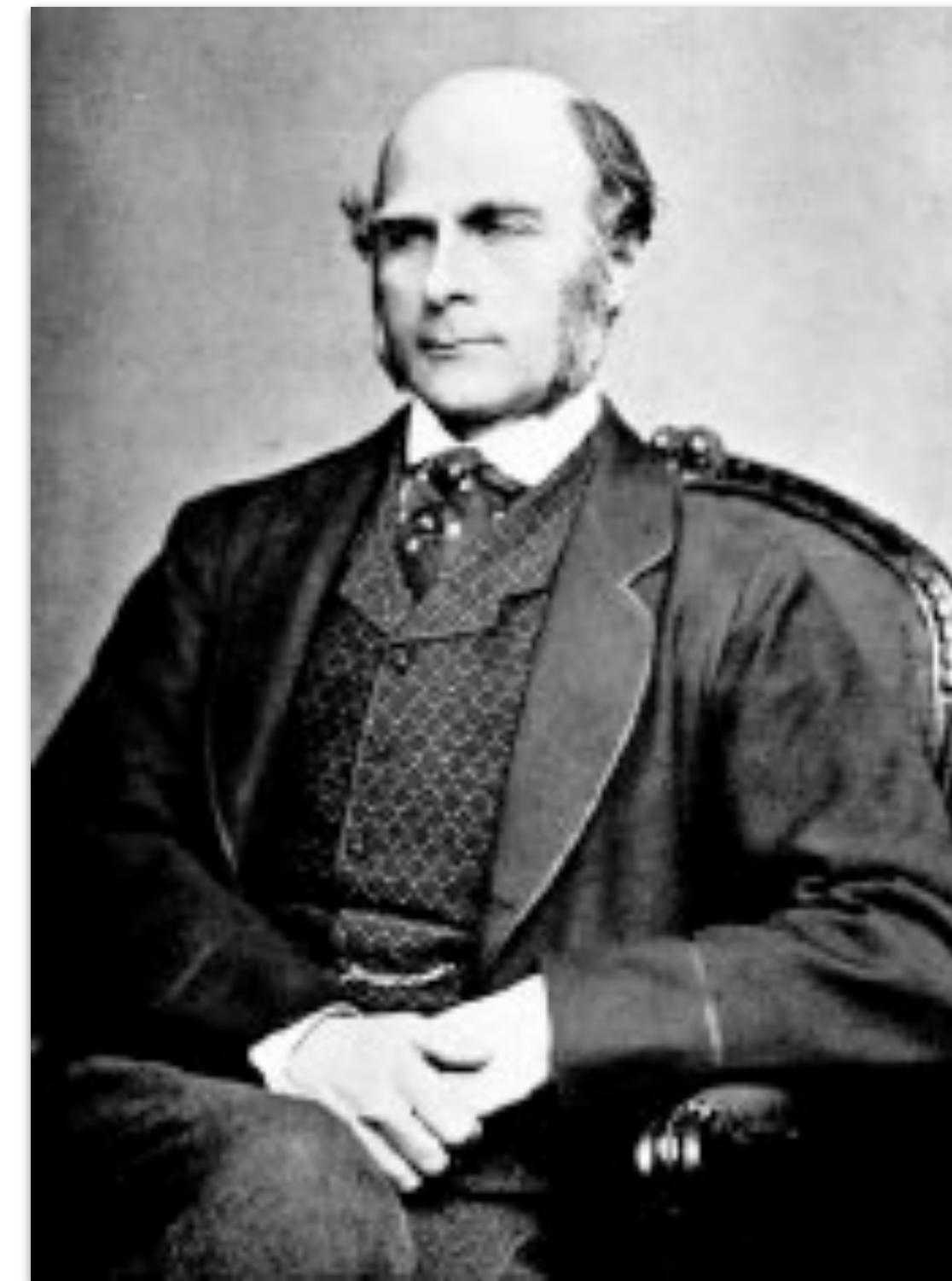


# History

**Sir Francis Galton (UK, 1888)**

Pioneering method of feature extraction.

Definition of **singular points** and  
**minutiae**, a.k.a. Galton's details  
(more details soon).



# History

Galton, F.  
*Finger Prints*  
MacMillan and Co., New York, 1892

## Sir Francis Galton (UK, 1888)

Pioneering method of feature extraction.

Publication of book “Finger Prints”,  
containing fundamental contributions to Biometrics.  
Estimate of 2 people presenting the  
same fingerprint: **1 in 64 billion**.

Book available at:  
<http://galton.org/books/finger-prints/galton-1892-fingerprints-1up.pdf>



# History

**Sir Francis Galton (UK, 1888)**  
Pioneer method of feature extraction.

**New York Times book review  
(Jan 1893)**

What Mr. Galton wants to show is that through the prints made by the finger tips we have an absolute method of identification. **As to that stupid thing, palmistry, our authority says it has no more significance than the creases on old clothes.**

**MR. GALTON ON FINGER PRINTS.**

FINGER PRINTS. By Francis Galton, F. R. S.  
New-York: Macmillan & Co.

Mr. Galton devotes his life to the elucidation of the queer and the curious. Undoubtedly there is nothing a man masters which is not of some benefit to his fellows, though centuries may elapse before the application comes. In his present volume Mr. Galton gives the results of a number of years of research, devoted to those tiny ridges of skin which appear in the ends of the fingers. They are the so-called "papillary" ridges. Carried away by his enthusiasm, Mr. Galton declares that these markings "are in some respects the most important of all anthropological data." He makes, too, the statement that they "have the unique merit of retaining all their peculiarities unchanged throughout life, and afford in consequence an incomparably surer criterion of identity than any other bodily feature."

The presence of these minute ridges on the finger tips became the subject of physiological study long ago. Strangely enough, they are perfectly defined in monkeys, but appear "in a much less advanced stage in other mammalia." We know that the finger tips are studded with pores. There are an infinite number of mouths always open which lead to ducts that secrete perspiration. The ridges must assist touch, as they "help in the discrimination of the character of surfaces that are variously rubbed as held between the fingers. These ridges are visible in the child unborn: they increase with the growth of the individual, and are sharply defined until old age sets in. Moderate work develops them, and they are visible on the toes. They are faintly developed in the hands of ladies." The ensuing statement used by Mr. Galton is not fortunate, for he adds that "they are not visible on the fingers of idiots of the lowest type, who are incapable of laboring at all."

What Mr. Galton wants to show is that through the prints made by the finger tips we have an absolute method of identification. As to that stupid thing, palmistry, our authority says it has no more significance than the creases on old clothes. The ridges Mr. Galton divides into three categories of arches, loops, and whorls, and his book abounds in curious pictures or finger prints, magnified by means of the camera. It seems to us to be terribly complex. As no two persons' finger tips are considered to be alike, and as there is individualism in the fingers of the right and left hand, and there are ten fingers in all, there would have to be ten distinct examinations before an identification could be positive.

When one comes to the real practical use of the finger-mark method it seems to have none. If there be any reliance to be put in it as a means of identification it would require an expert having uncommon powers of observation. When we are told that there are "about thirty-five points [of resemblance] situated on the bulb of each of the ten digits, in addition to more than 100 on the ball of the thumb," it may be seen how troublesome the matter is likely to be. Then, as one has to work up over a thousand points on his own hands, or on somebody else's hands, hours, days, and weeks might elapse before anything like a conclusion could be reached. Scientifically, when further treated, the subject may be of minor interest; practically, it has none at all. The book, of course, shows that diligence and hard work which are common to everything Mr. Galton does, but, really, "the play is not worth the candle."

The New York Times  
Published: January 1, 1893  
Copyright © The New York Times

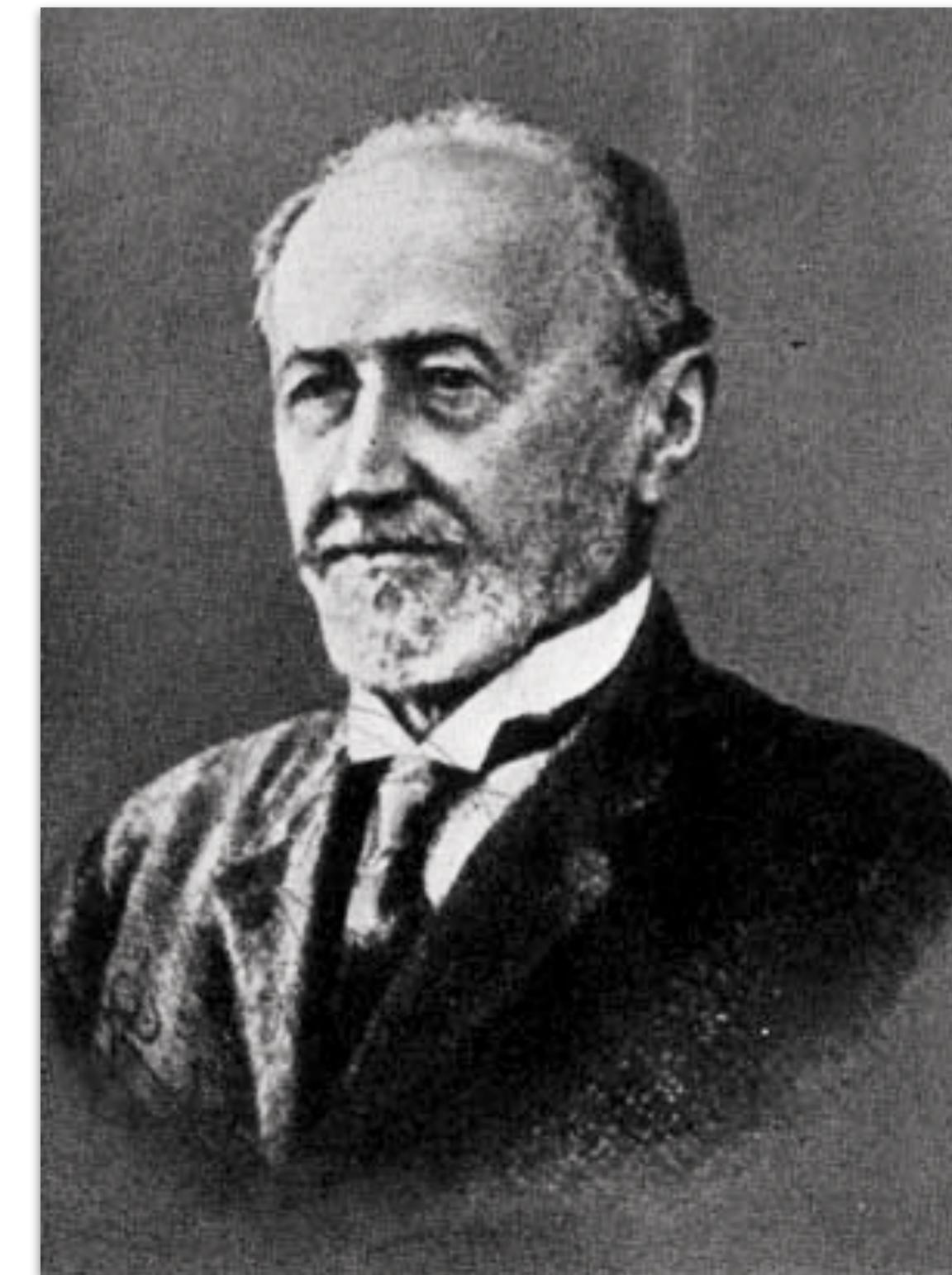
# History

**Juan Vucetich (Argentina, 1892)**

Pioneering criminal conviction based  
on fingerprints.

**Rojas case**

Woman accused of murder  
based on bloody fingerprint  
left at crime scene.



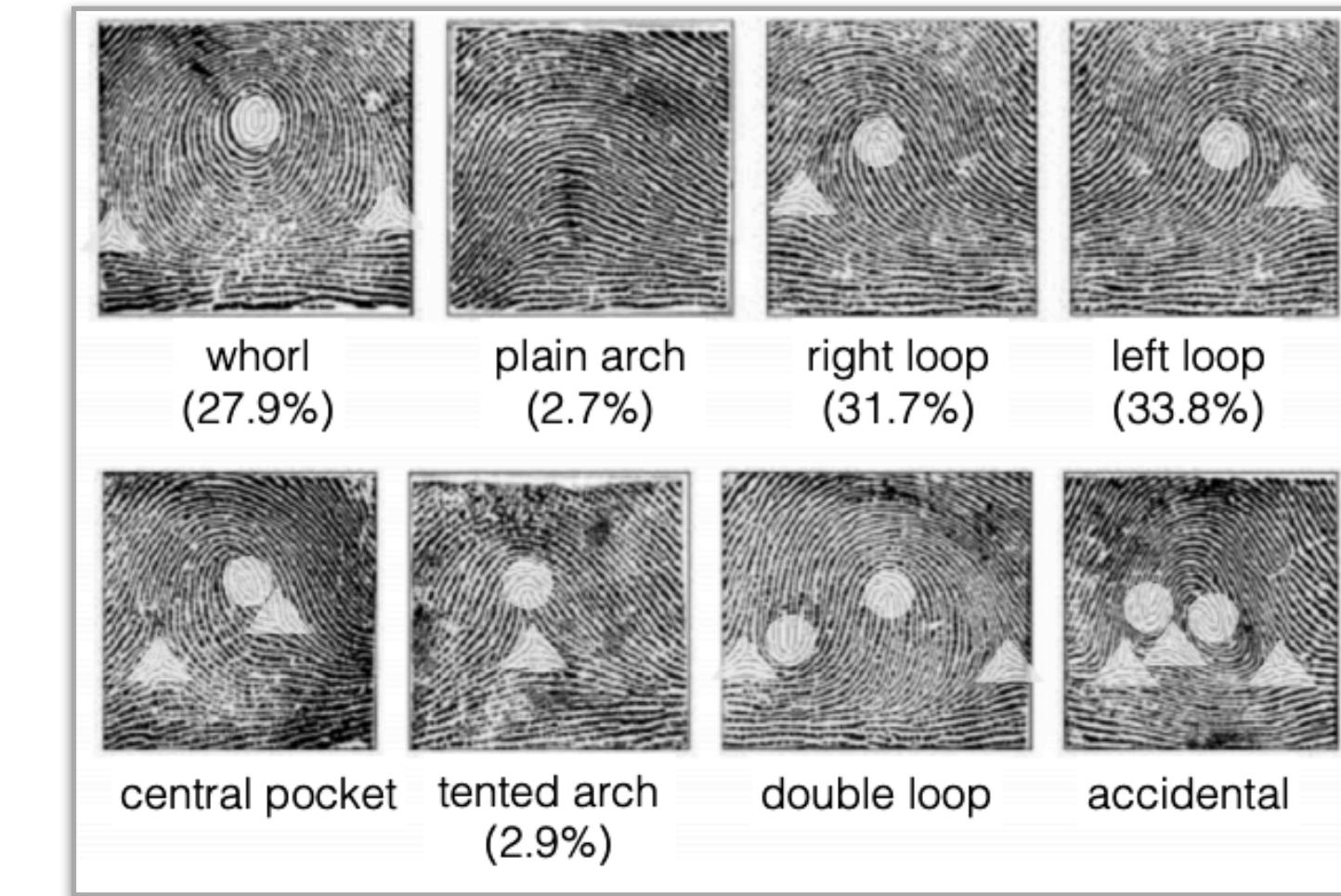
# History

## Sir Edward Henry (UK, 1897)

Pioneering fingerprint classification and indexing method.

## Work at Calcutta, India

Speeded up the process of searching for fingerprints.



Henry's fingerprint classification.

# History

**Edmond Locard (France, 1910)**

Pioneering methodology  
to be adopted in court.

A defendant should be pronounced guilty if at least 12 features match in the sample and reference material.



# History

## XX-Century Acceptance

**Scotland Yard, 1903**

Fingerprints start to be officially used.



**International Association for Identification, 1915**

Creation of the largest forensic association in the world.



**FBI, 1924**

Fingerprint Identification Division is established.



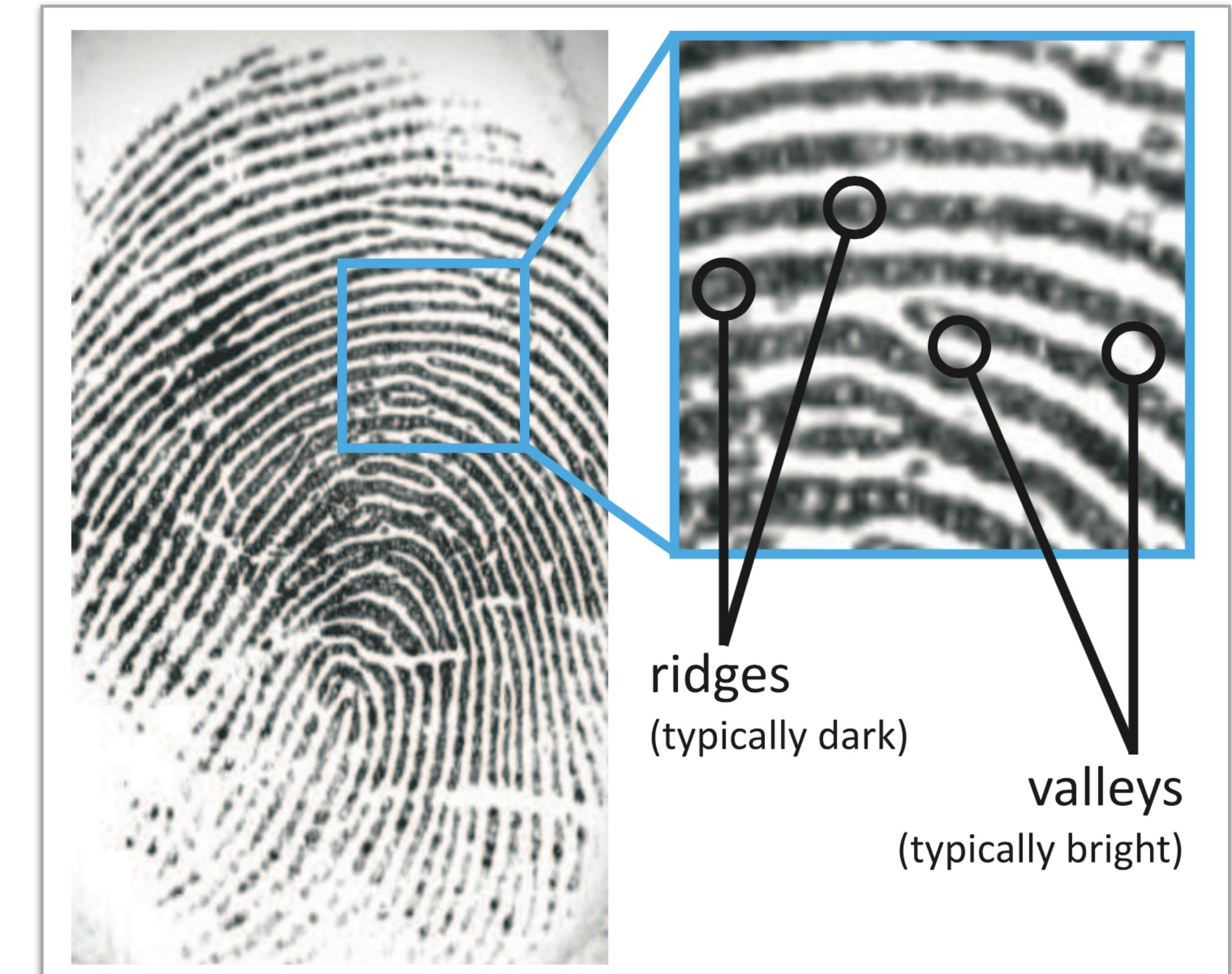
# Features

**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



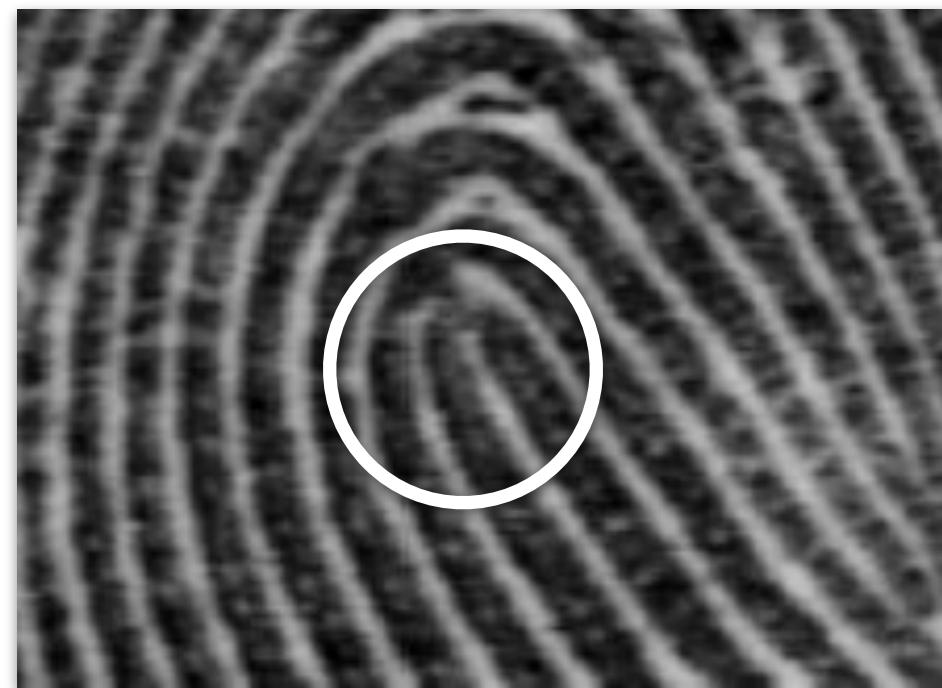
# Features

## Level-1 Features

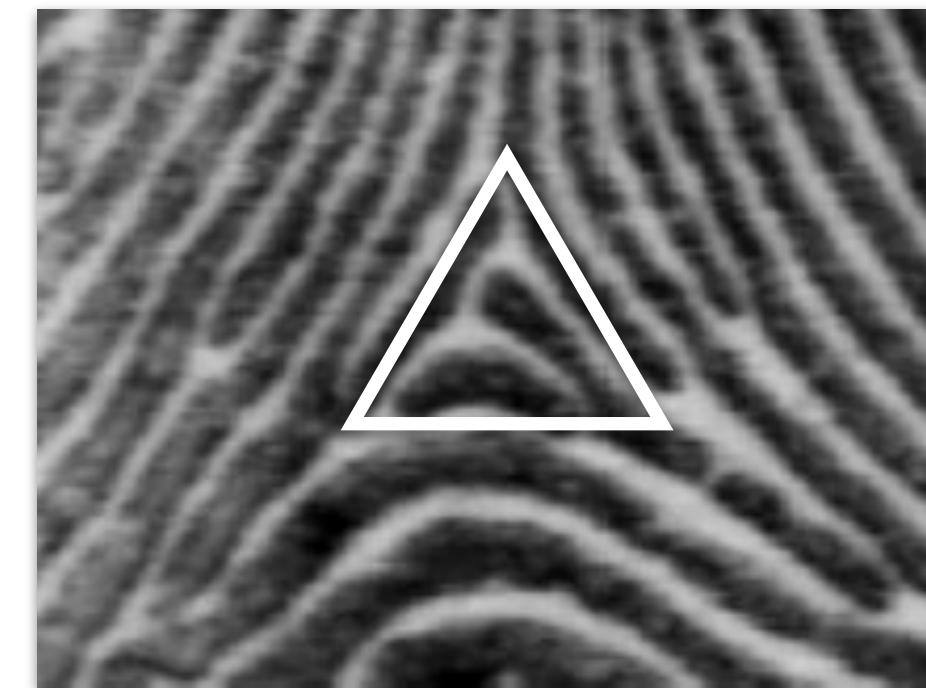
Observe singular points and core.

Useful capture resolution: 250 ppi (pixels per inch)

## Singular Points



loop



delta

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

## Core

Up-most singular point

or (in case of no singular point)

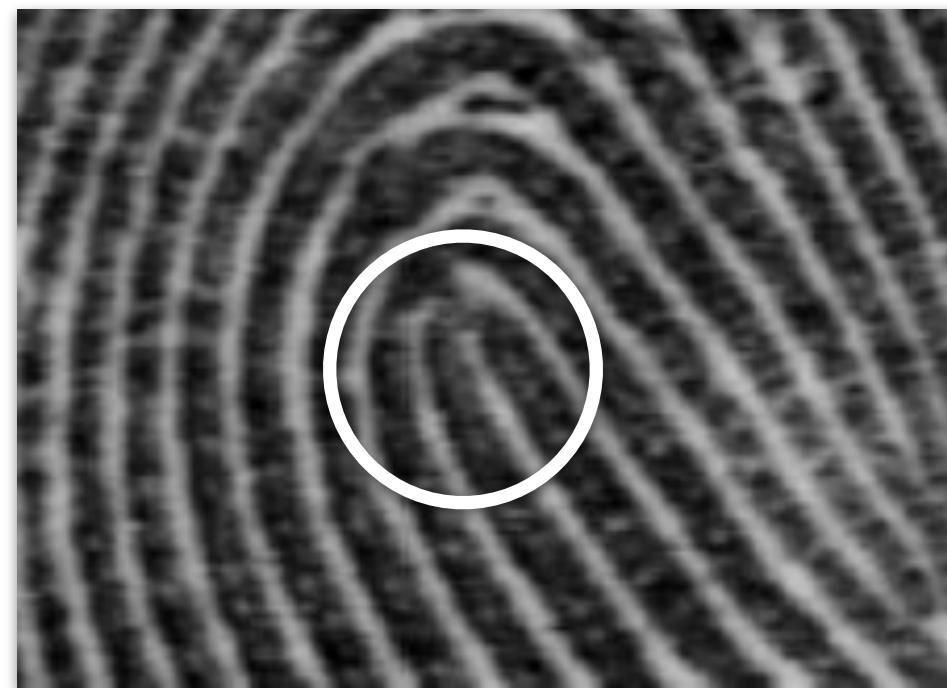
Point of maximum ridge curvature.

# Features

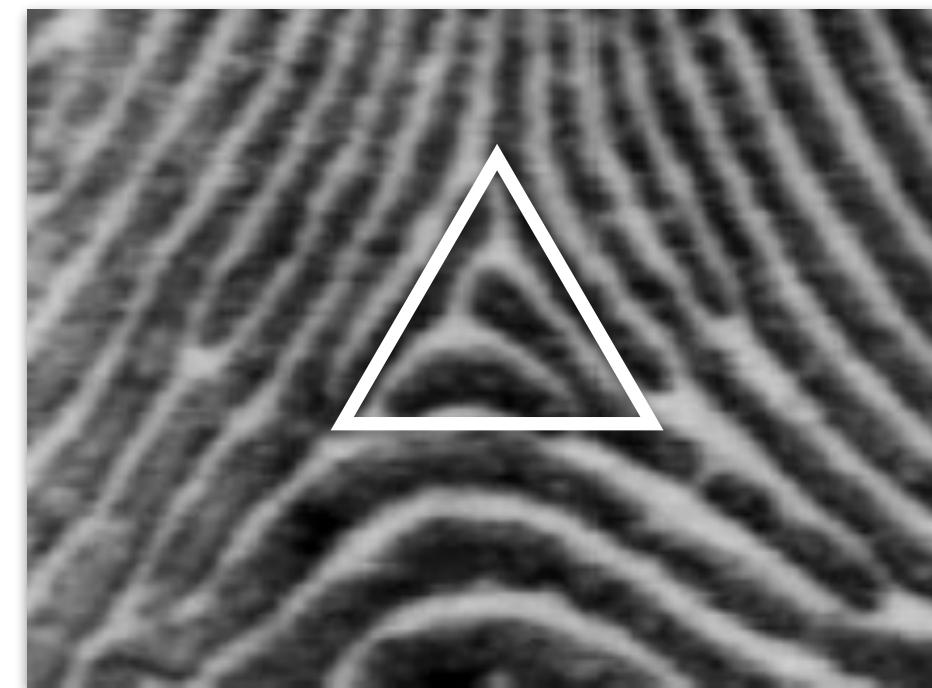
## Level-1 Features

Observe singular points and core.

## Usage of Singular Points and Core



loop



delta

Jain, Ross, and Nandakumar  
*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%

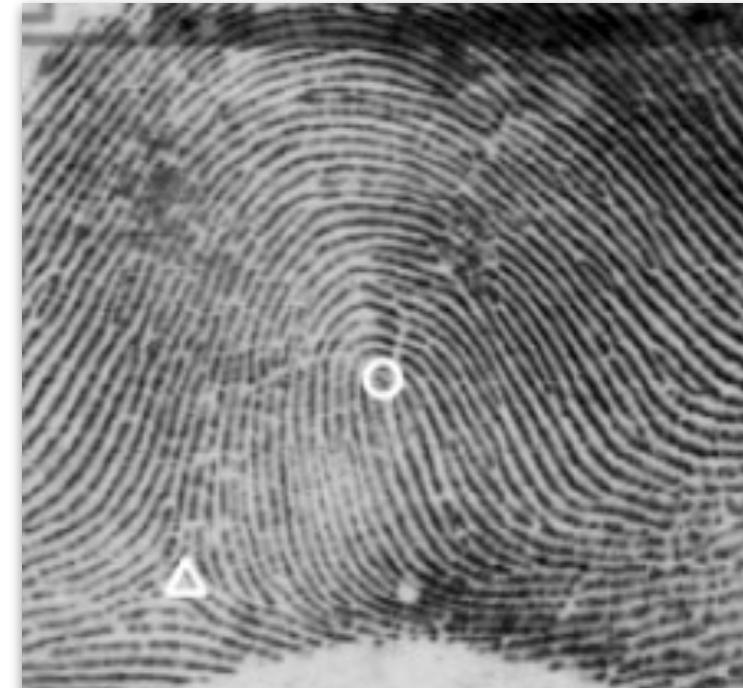


tented arch  
3%



left loop

65%



right loop

65%



whorl  
24%



twin loop  
4%

Percentages: frequencies of observation.

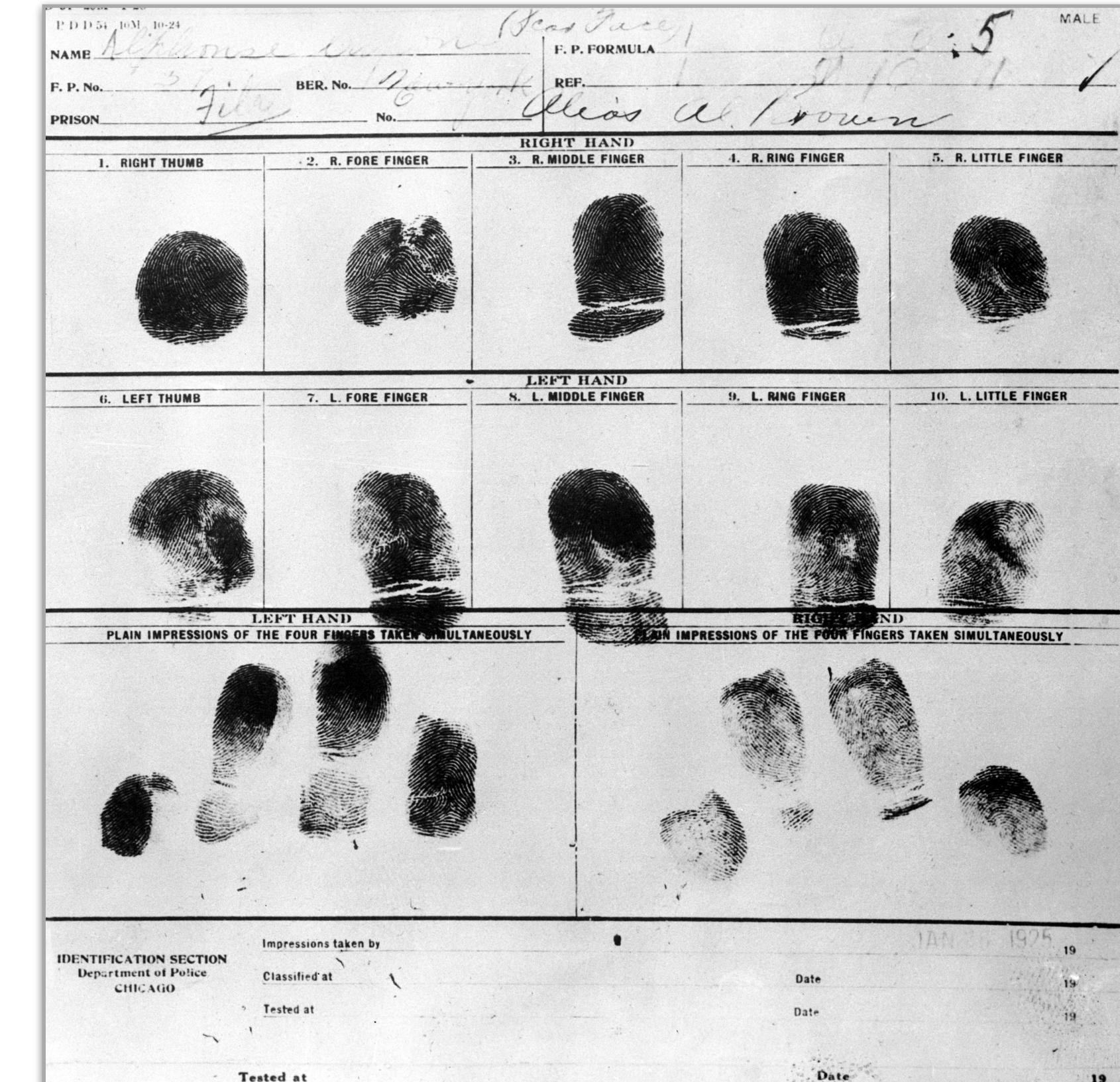
# Features

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.



# Features

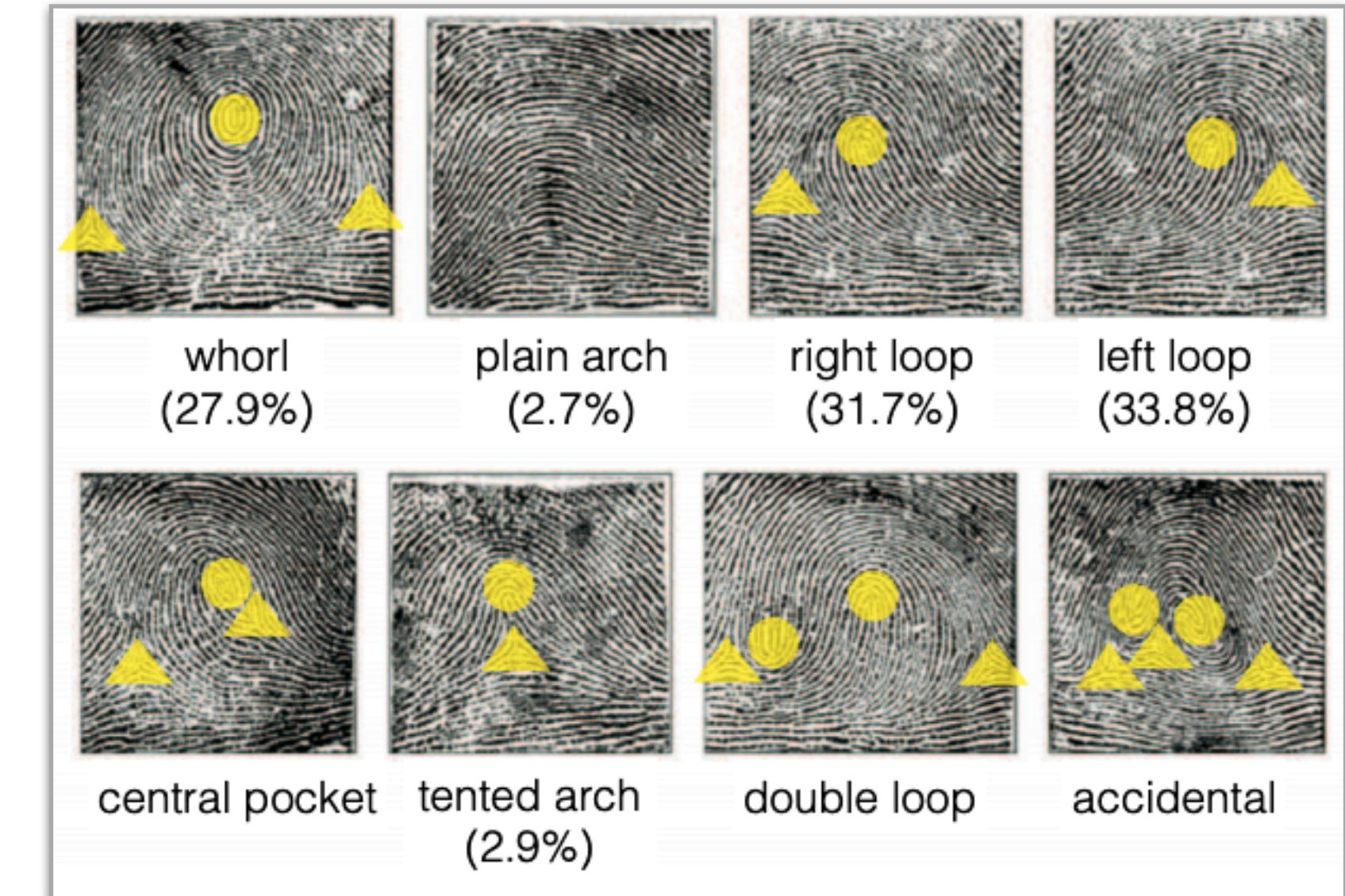
**How useful are level-1 features?**

**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

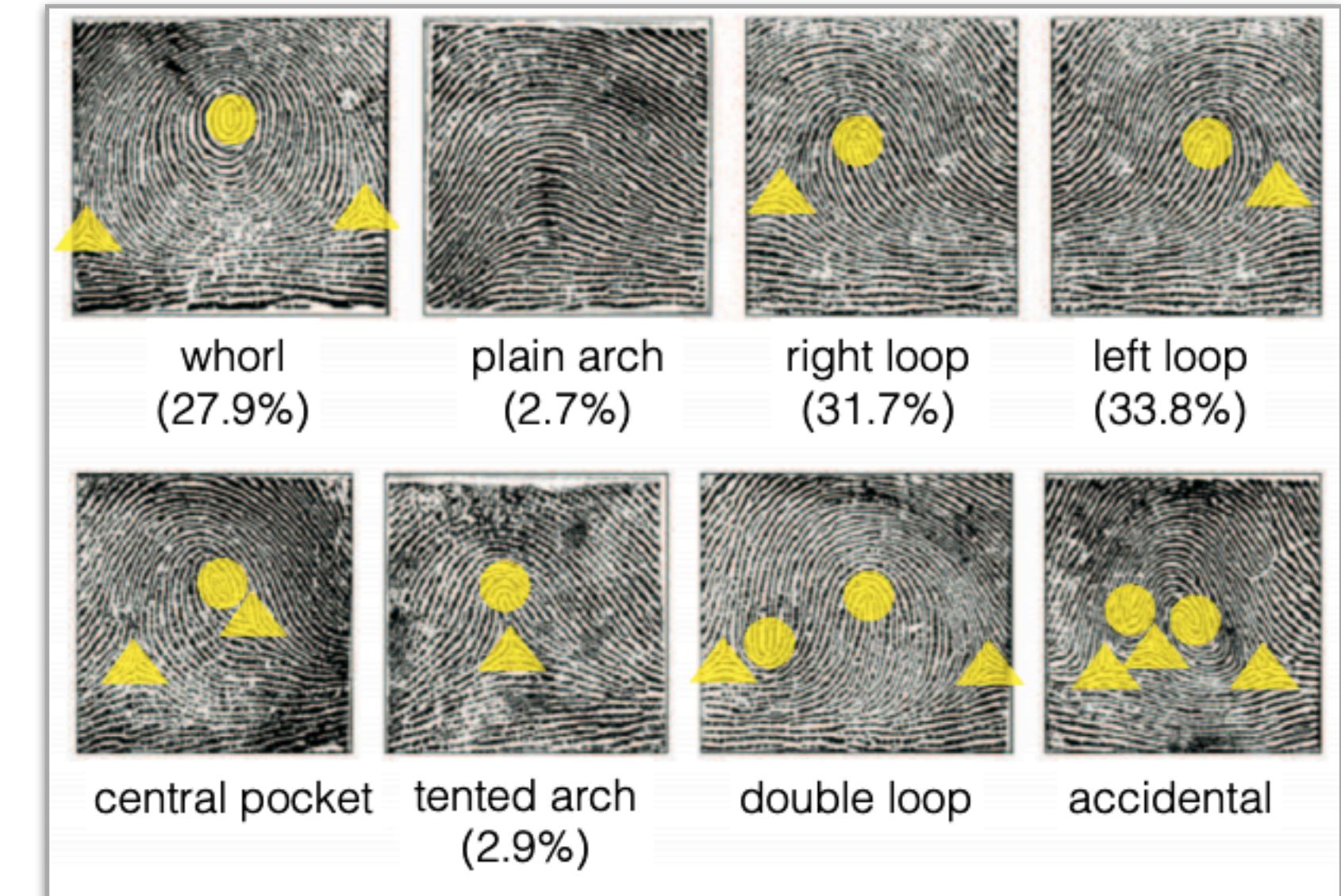
**How useful are level-1 features?**

**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



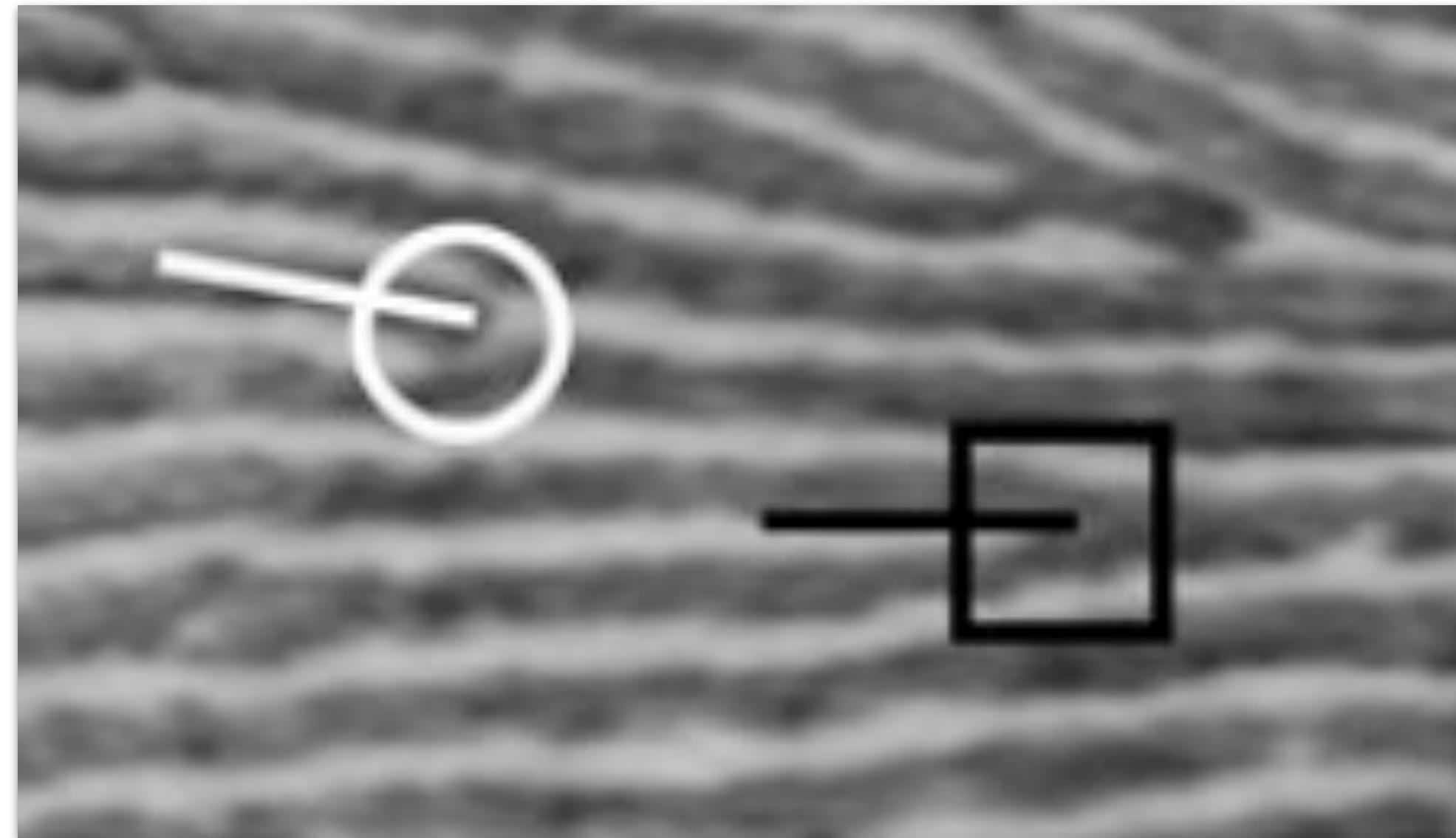
# Features

## Level-2 Features

Observe minutiae (Galton's details).

Useful capture resolution: 500 ppi

Ridge Ending



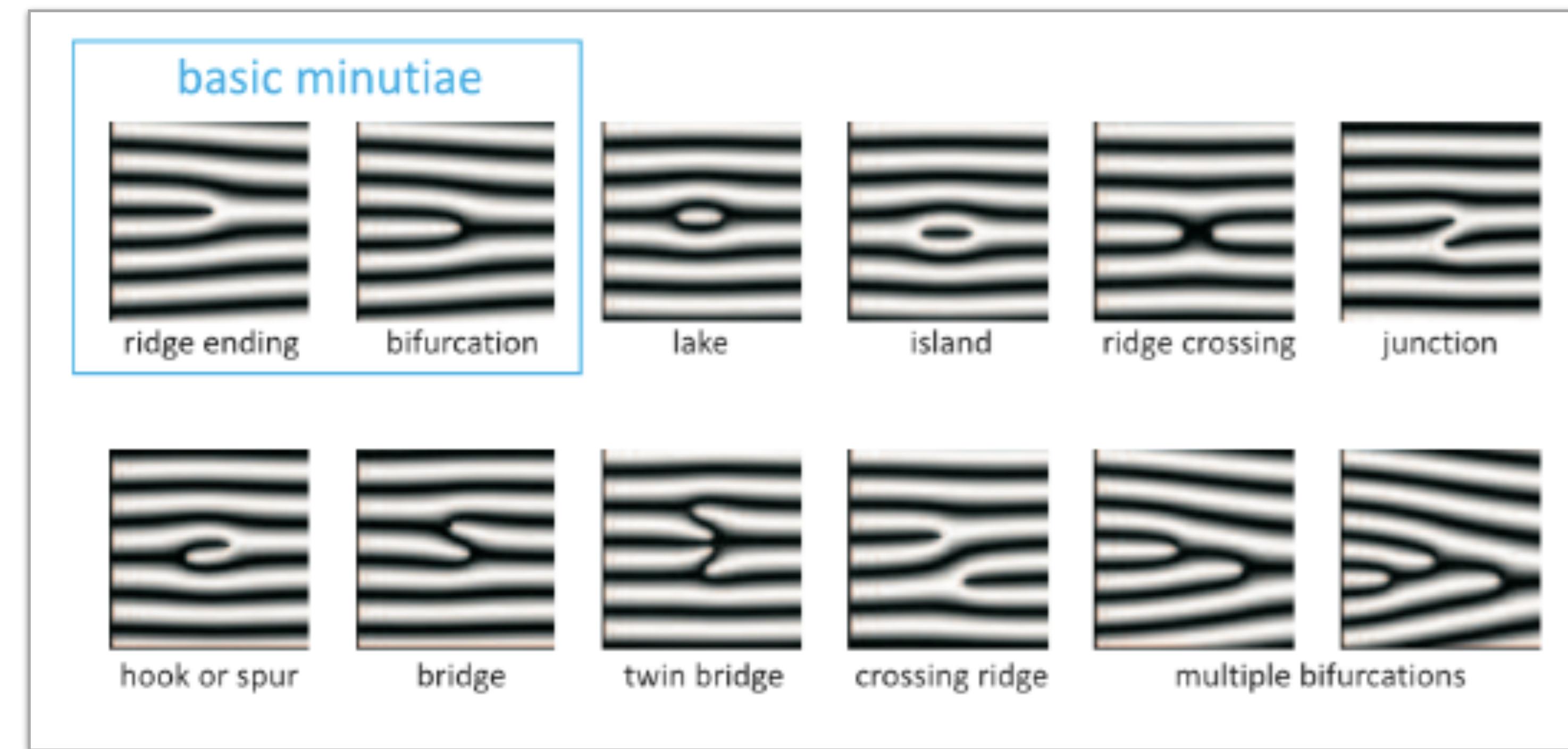
Ridge Bifurcation

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

# Features

## Level-2 Features

Alternative minutiae.



Source:  
[www.optel.com.pl](http://www.optel.com.pl)

# Features

## Level-2 Features

**Usage of minutiae**  
Fingerprint matching.

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

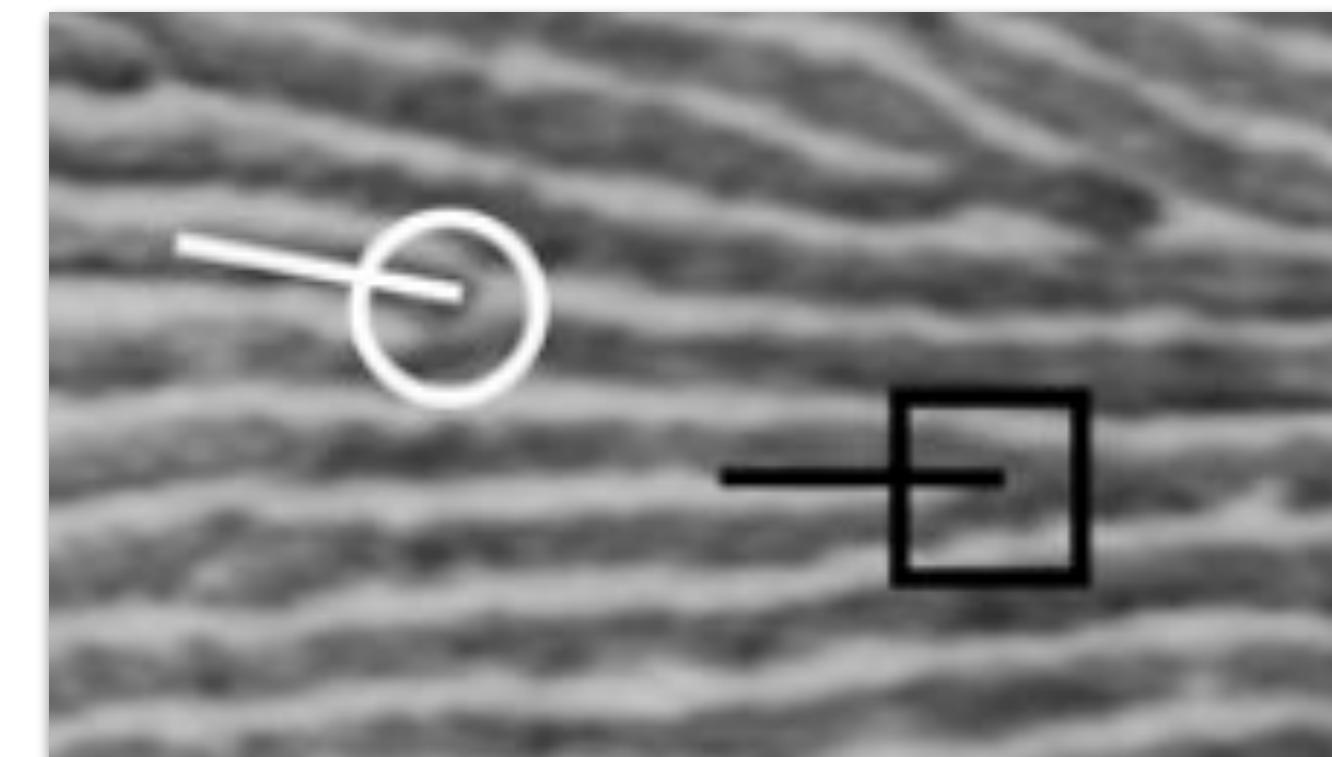


# Features

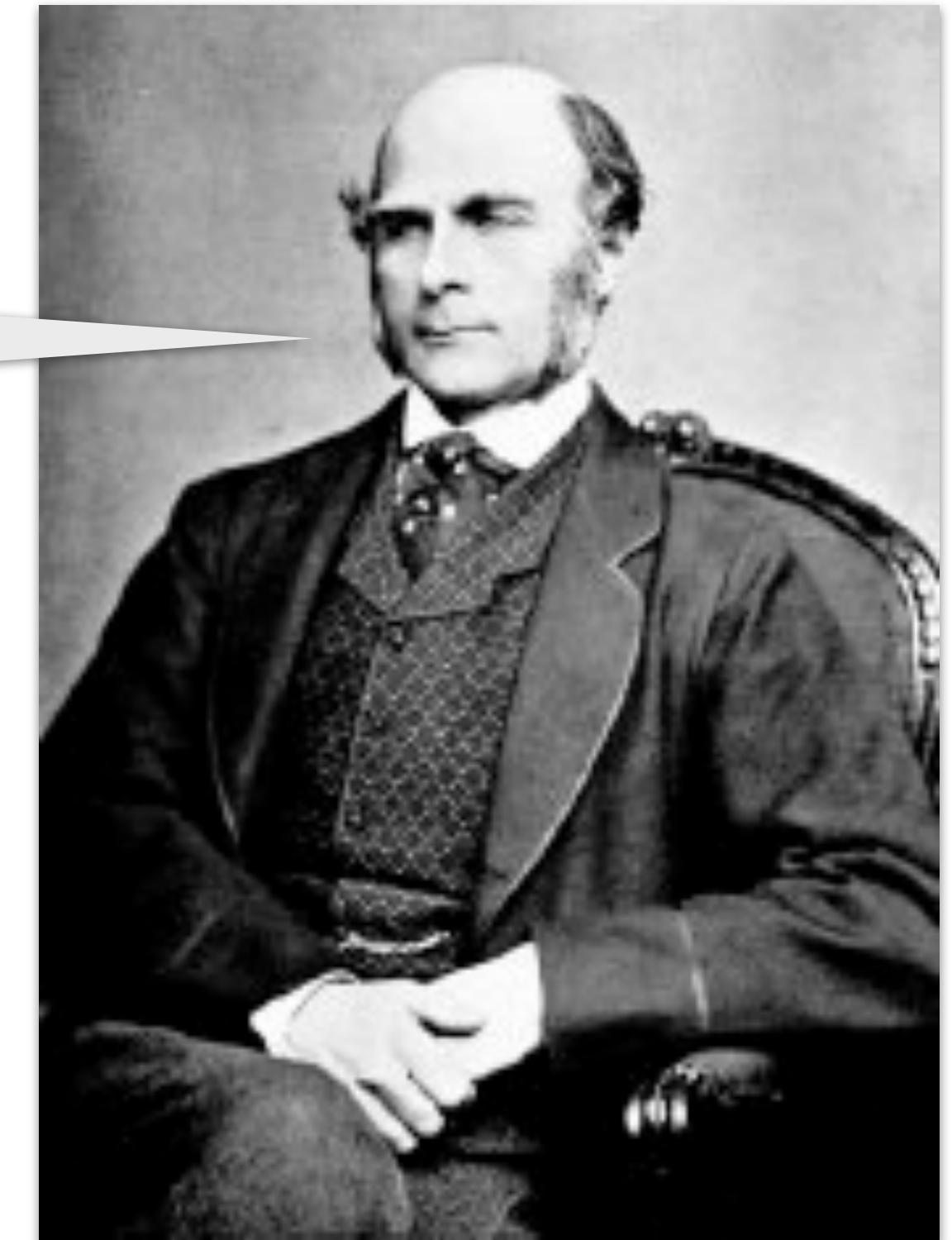
## Level-2 Features

### 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



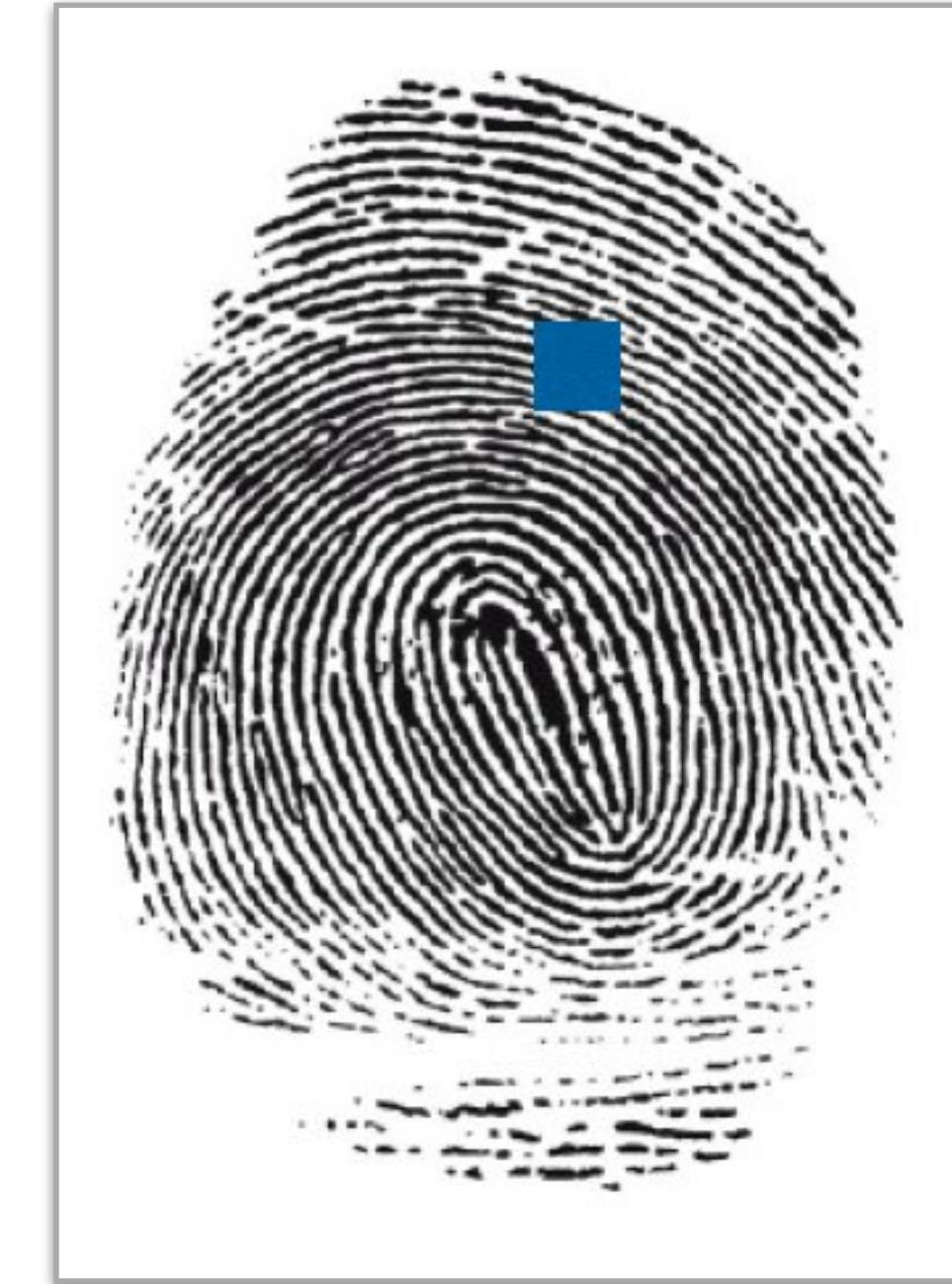
# Features

## 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

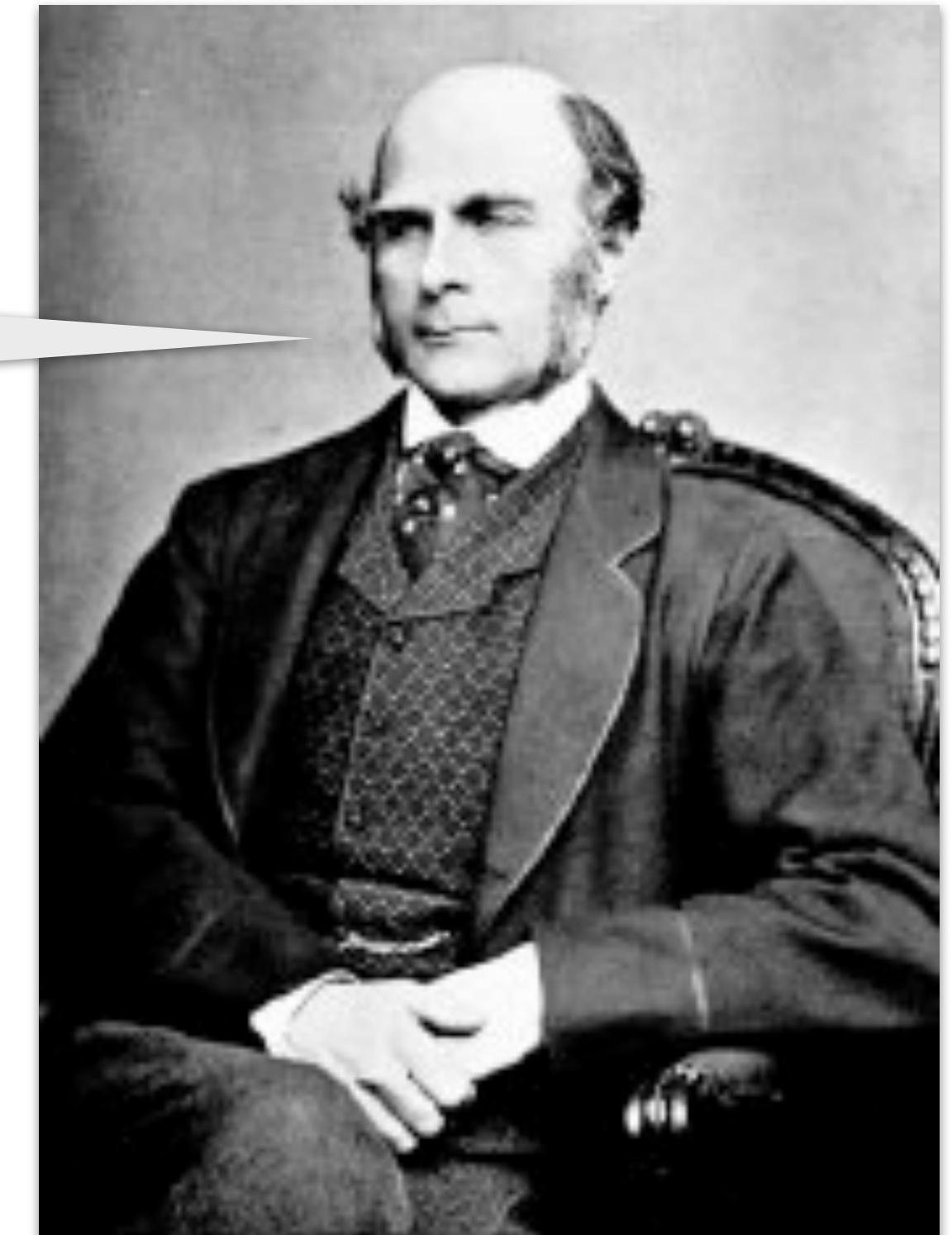
## Level-2 Features

### Galton's Estimate

#### 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?

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



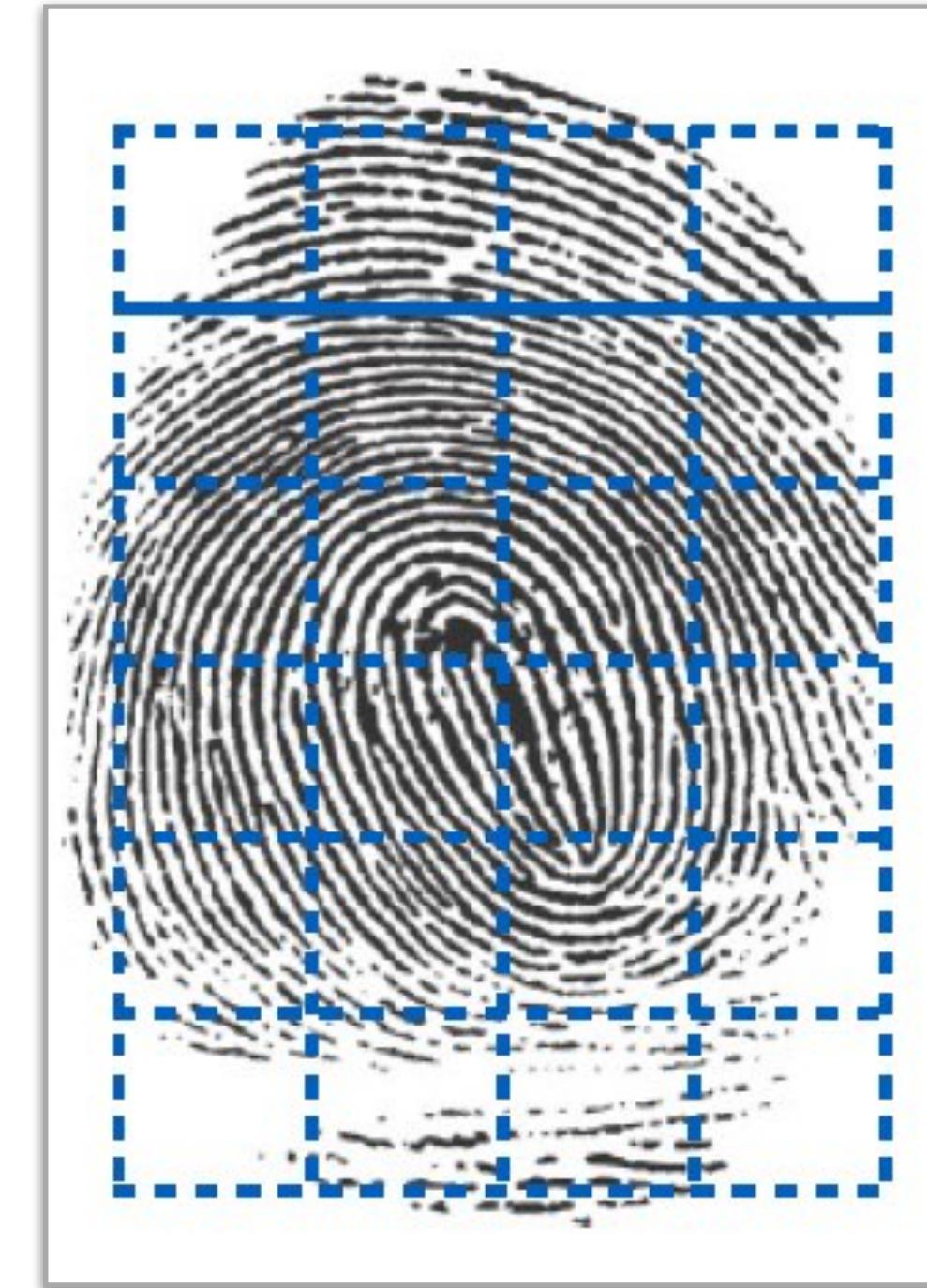
# Features

## Level-2 Features

### Galton's Estimate

A typical fingerprint consists of 24 six-ridge squares.

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



Source:  
Dr. Walter Scheirer

# Features

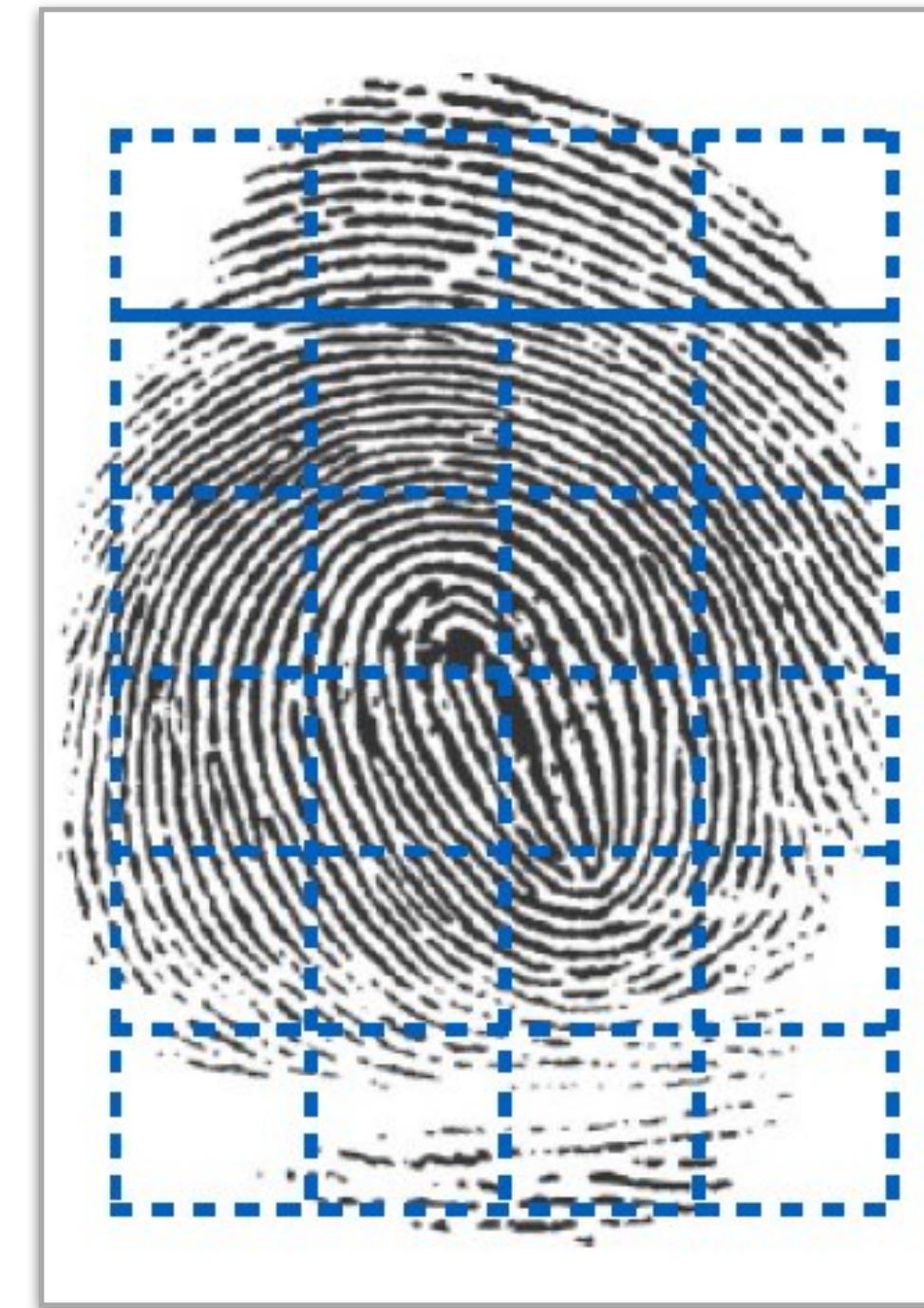
## Level-2 Features

### Galton's Estimate

For each square:

Chance of correct guess of #ridges  
entering and leaving leaving it:  $1/2^8$

Chance of correct guess of the  
course of ridges within it:  $1/2^4$



Source:  
Dr. Walter Scheirer

# Features

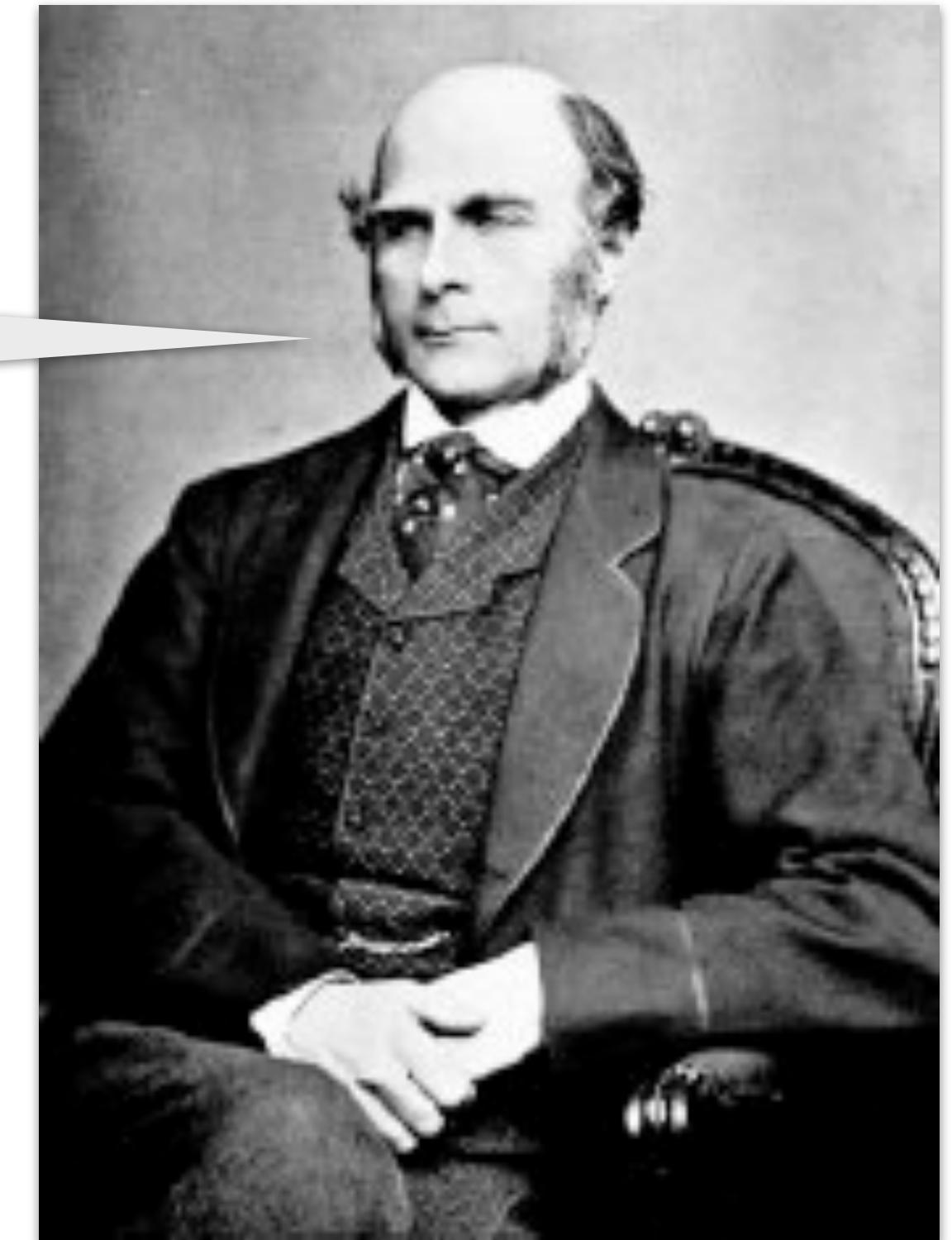
## Level-2 Features

### Galton's Estimate

Total chance of a random fingerprint  
match a particular one:

$$1/2^{24} \times 1/2^8 \times 1/2^4 = 1/2^{36}$$

1 in 64 billion



# Features

## Level-2 Features

### Galton's Estimate

Total chance of a random fingerprint  
match a particular one:

$$1/2^{24} \times 1/2^8 \times 1/2^4 = 1/2^{36}$$

How many humans  
have ever lived?

107 billion

[https://www.bbc.com/  
news/magazine-16870579](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**

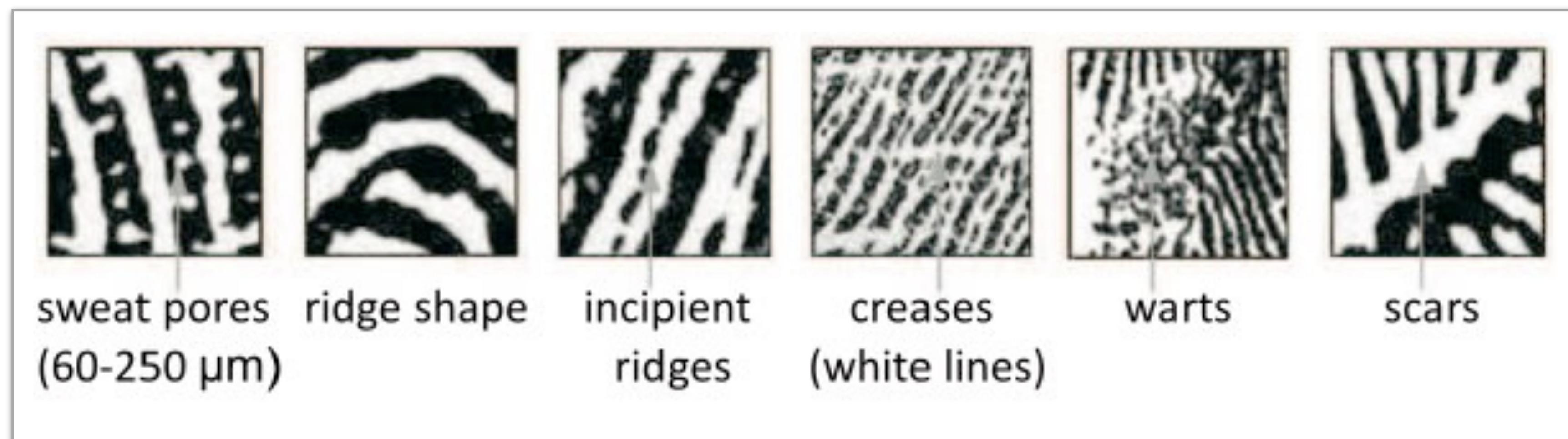


# Features

## 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>

# S'up Next?

## More about fingerprints

Fingerprint acquisition methods.

Fingerprint enhancement methods.

Fingerprint data representation.



## **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/>