

# **Fingerprint Recognition I**

**COMP 388-002/488-002 Biometrics**

**Daniel Moreira**  
Fall 2023



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# Today you will...

*Get to know*  
Biometric system attacks (*pending*).  
The history of the usage of fingerprints.  
Useful fingerprint features.

# Today's attendance

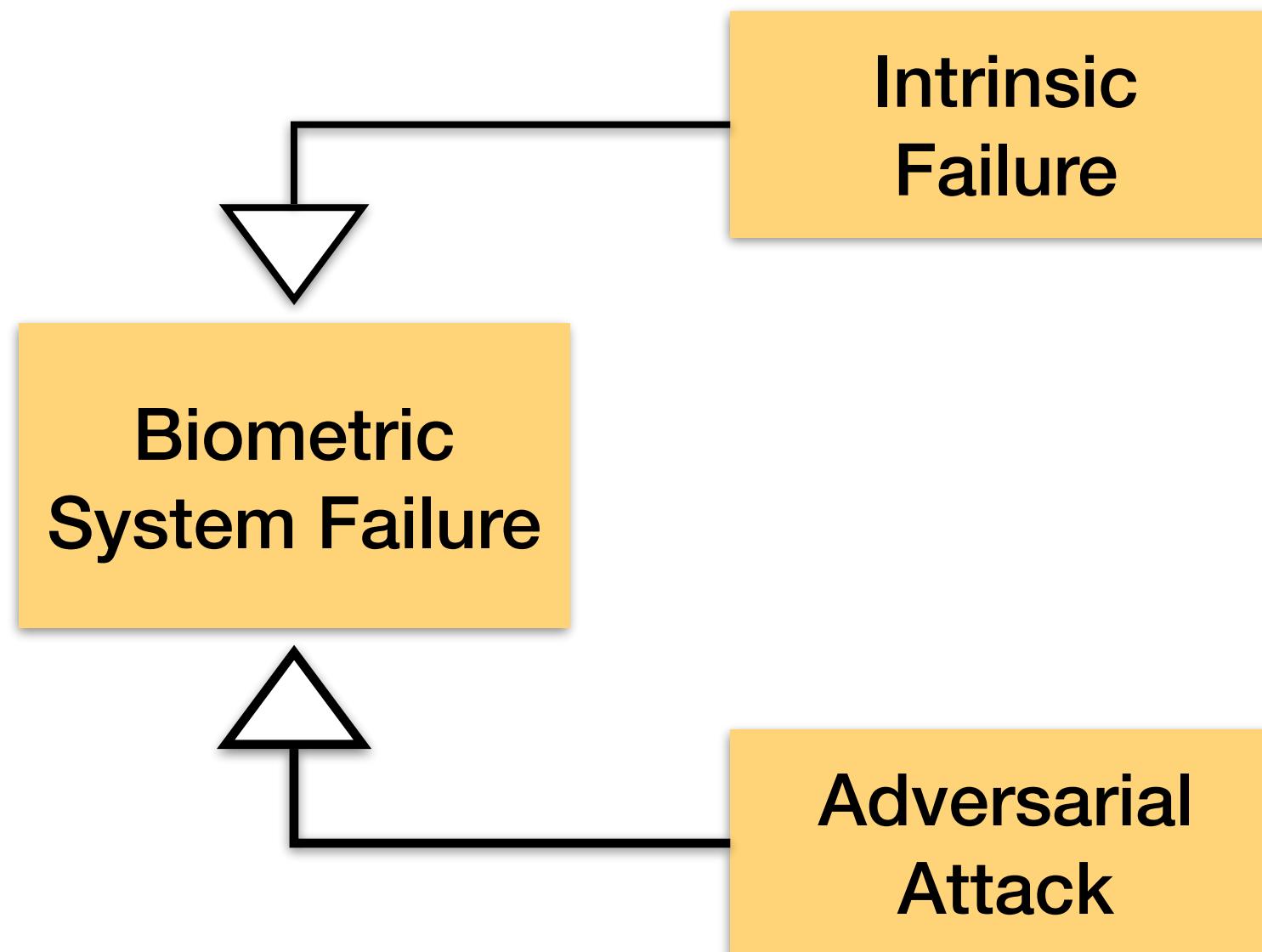
Please fill out the form

<https://forms.gle/s5jTkByMXAFNd1Nn8>



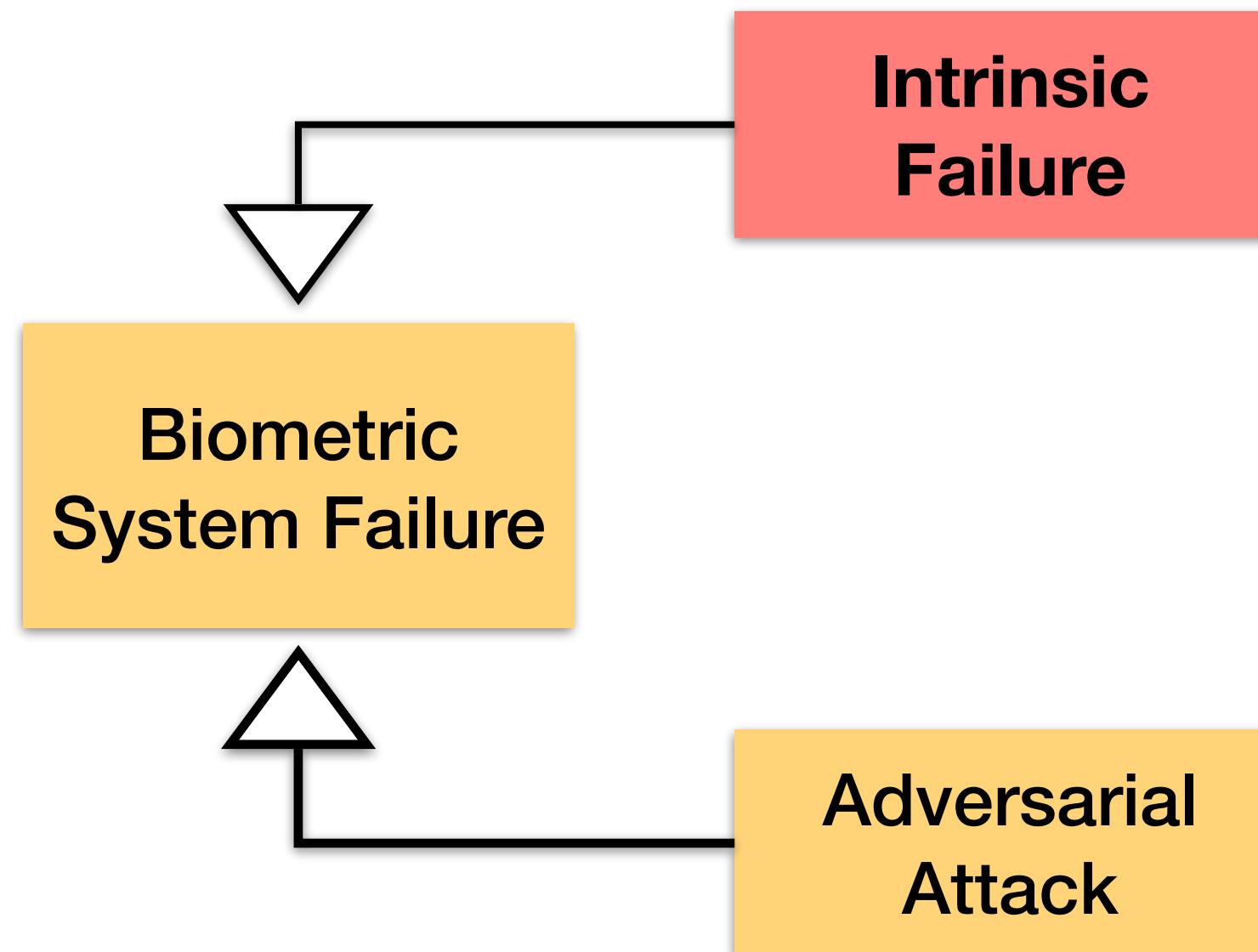
# Biometric System Attacks

## Threat Model



# Biometric System Attacks

## Threat Model



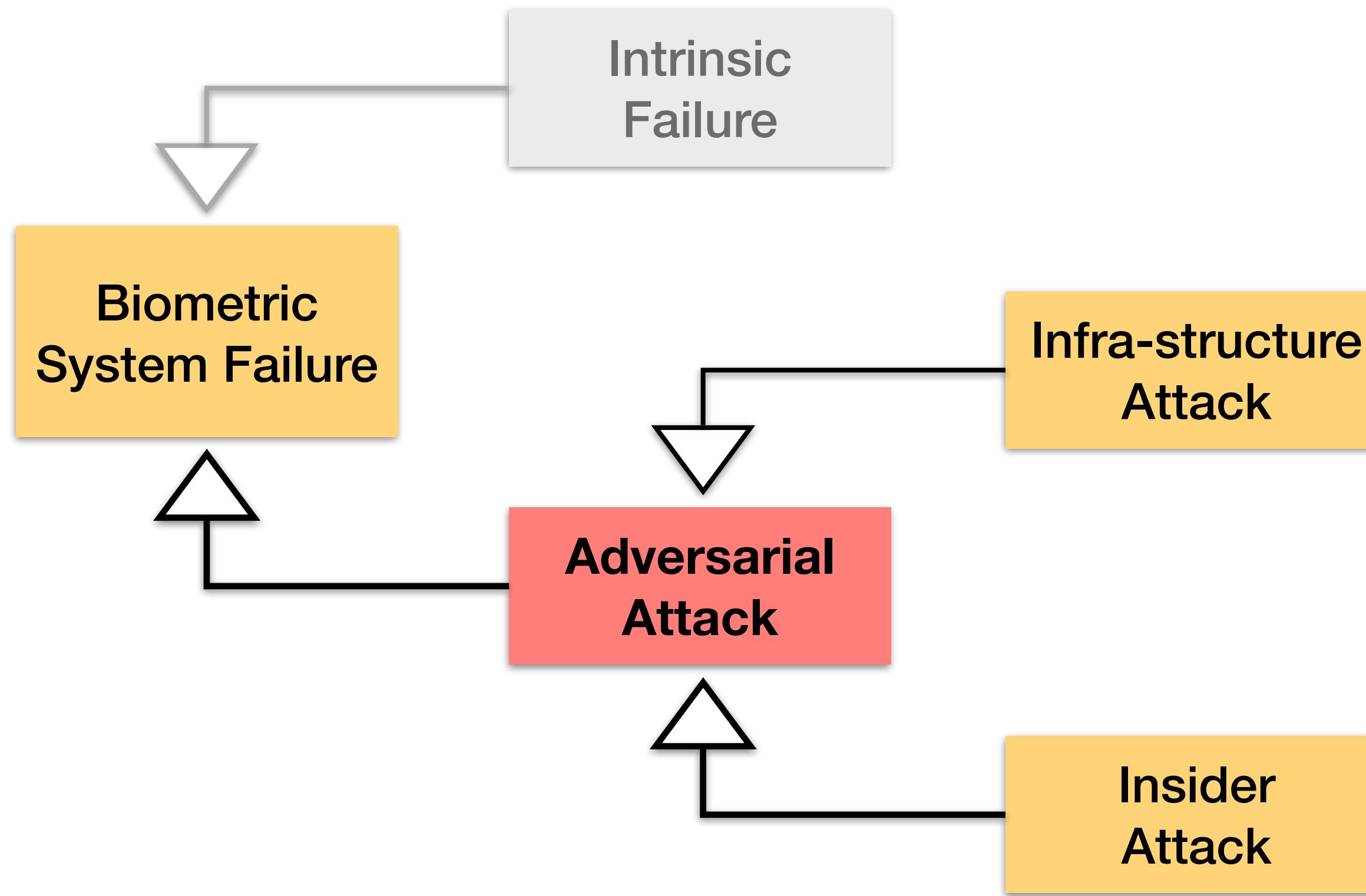
### Not attacks

Errors due to the limitation of the solutions and due to hardware stress.



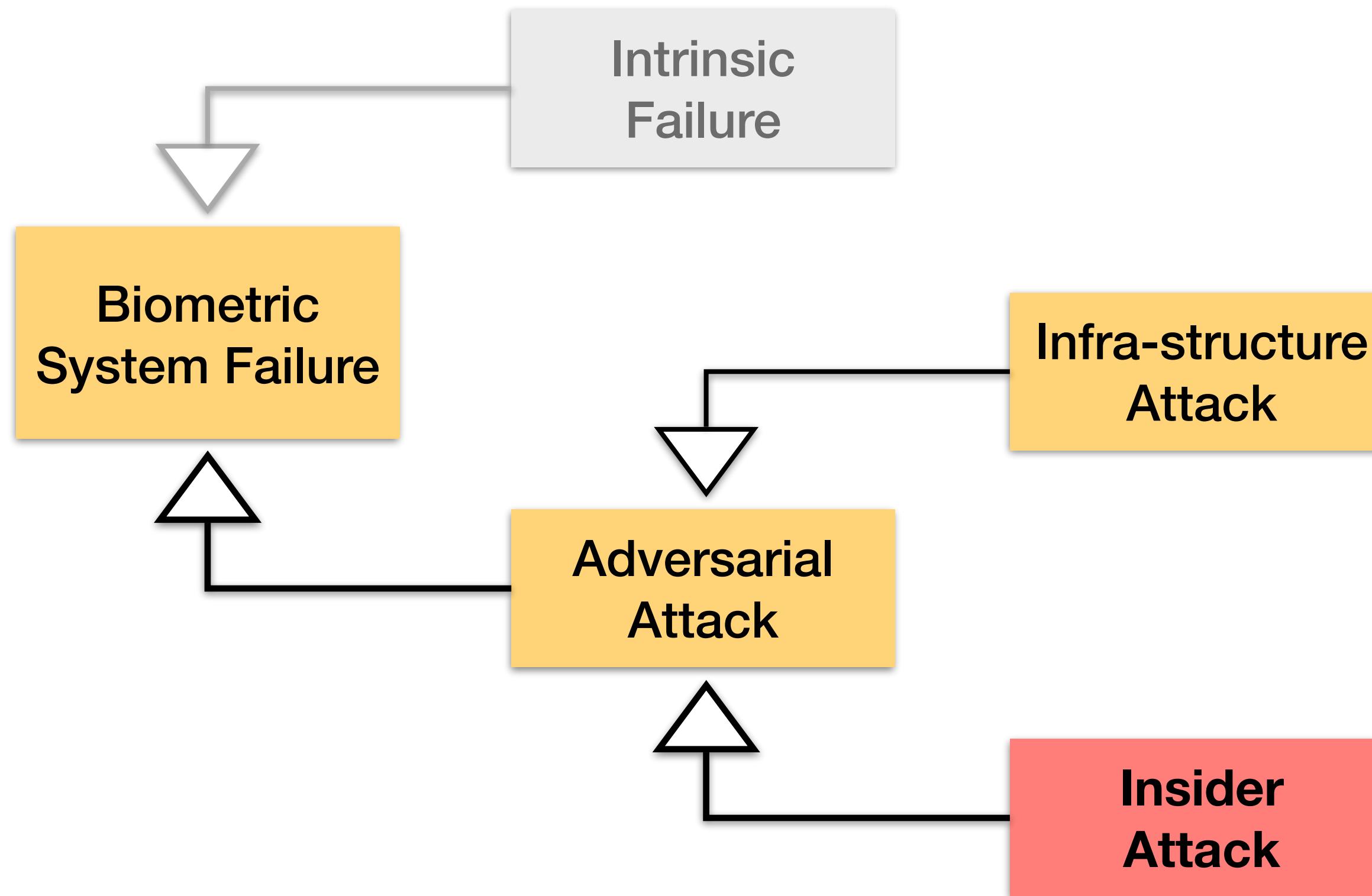
# Biometric System Attacks

## Threat Model



# Biometric System Attacks

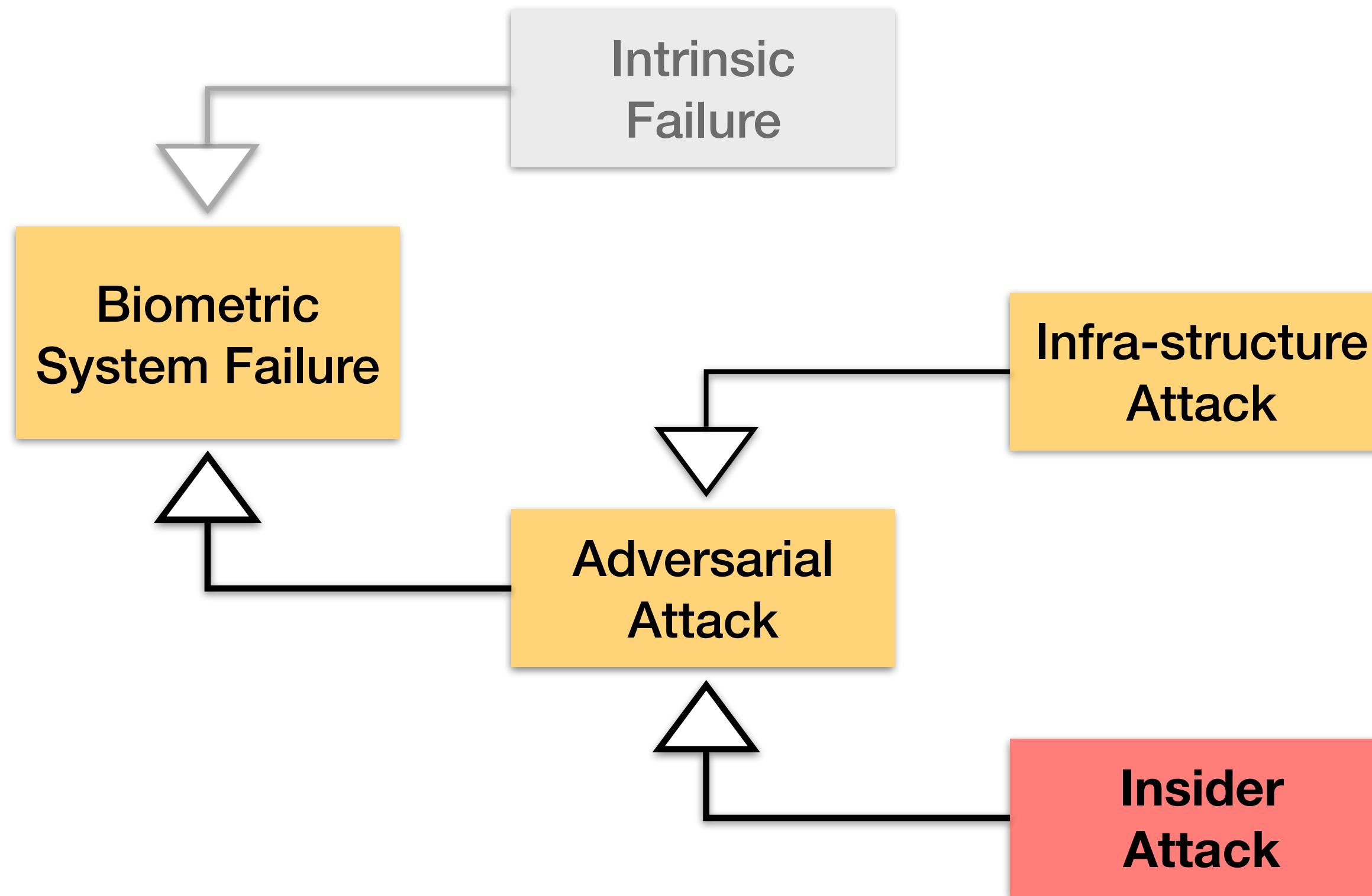
## Threat Model



**Friendly Fire**  
Attacks from *insiders*  
(system users or operators).  
*What can we do?*

# Biometric System Attacks

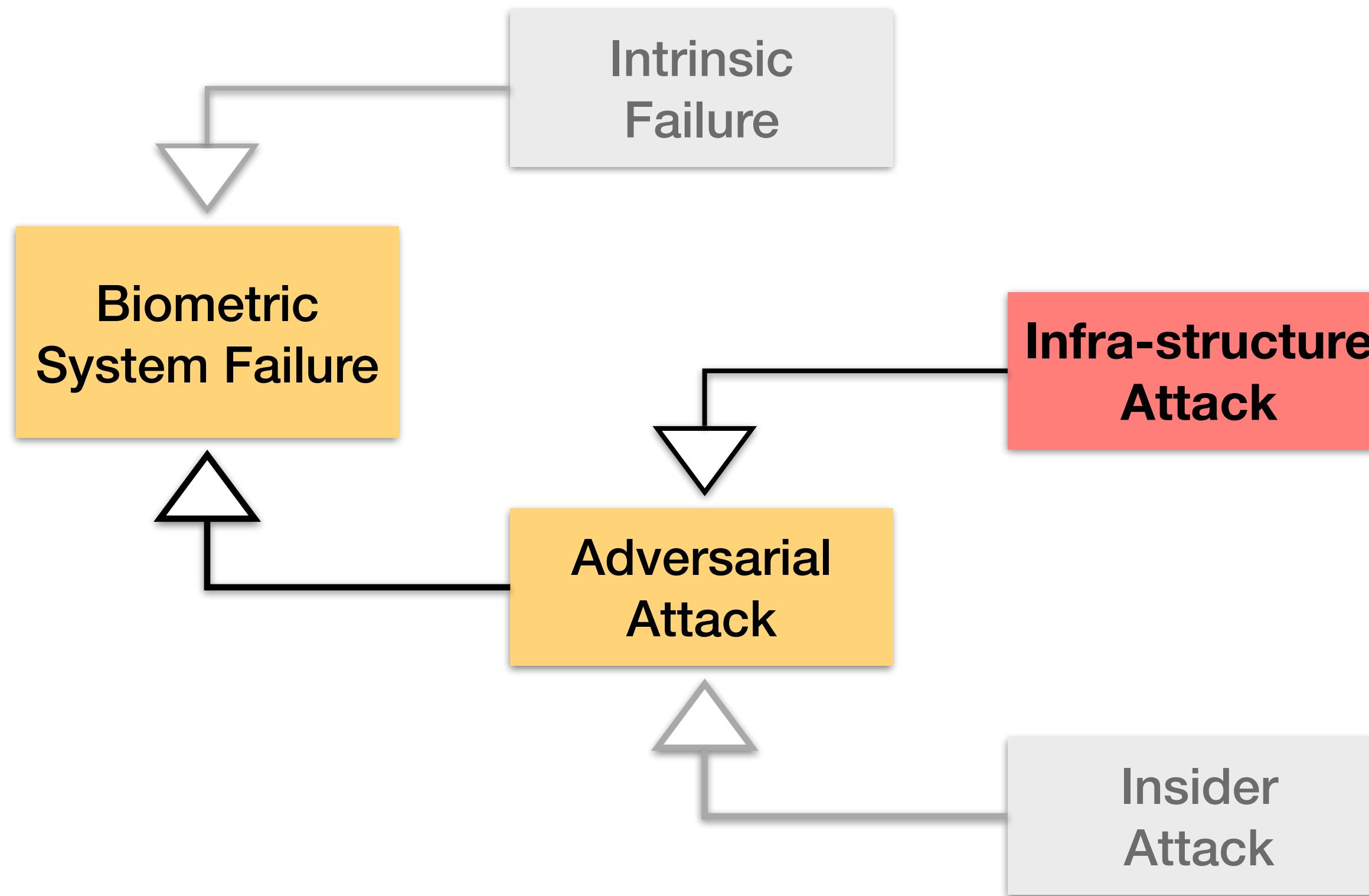
## Threat Model



**Friendly Fire**  
Attacks from *insiders*  
(system users or operators).  
Keep your system logs in  
good shape.

# Biometric System Attacks

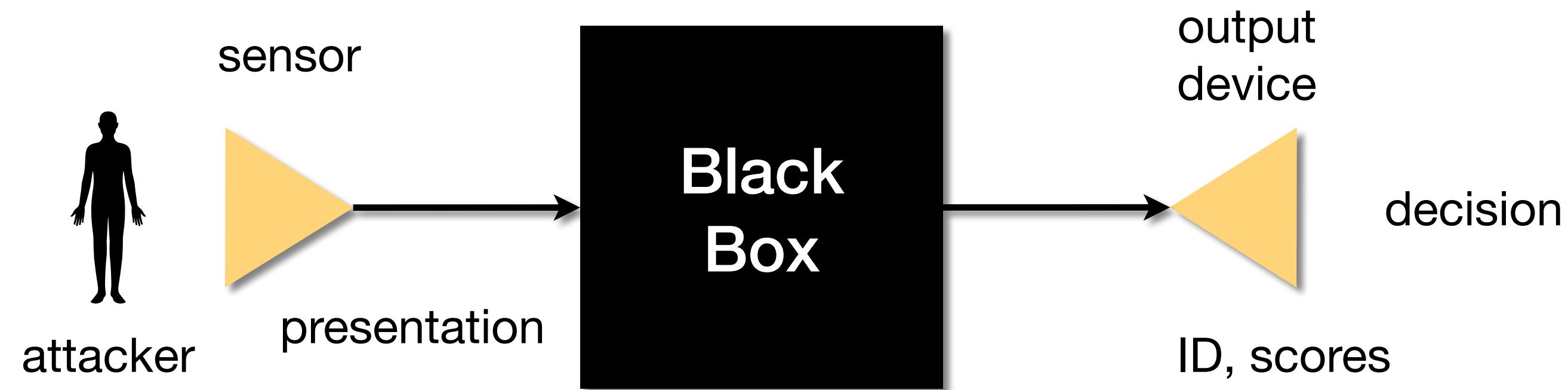
## Threat Model



**Types**  
Black box  
White box

# Biometric System Attacks

## Black Box Attack



## Examples

- Impersonation
- Obfuscation
- Spoofing

# Biometric System Attacks

## Impersonation

When the attacker pretends to have somebody else's trait.  
*What can we do?*



The screenshot shows a news article from Click2Houston.com. The header includes the Click2Houston logo, weather (54°F), sign-in options, and navigation links for NEWS, SPORTS, THINGS TO DO, FIND YOUR CITY, DISCOVER, HOUSTON LIFE, WEATHER, TRAFFIC, and NEWSLETTER. A blue banner at the top says "KPRC 2 News at 6". The main headline is "Divorce deception: Man forges wife's name on divorce papers, police say". Below the headline, it says "A Houston man now has to answer to his wife and the courts. Harris County Precinct 4 deputies said Paul Nixon, 51, tried to deceive the Harris County District Clerk's office by forging his wife's signature on divorce papers." The author is Taisha Walker, Reporter, and it was published on September 18, 2019, at 6:57 pm.

<https://www.click2houston.com/news/2019/09/18/divorce-deception-man-forges-wifes-name-on-divorce-papers-police-say/>



# Biometric System Attacks

## Impersonation

When the attacker pretends to have somebody else's trait.

Possible solution: use more than one trait (Multibiometrics).



The screenshot shows a news article from Click2Houston.com. The header includes the station logo 'Click2Houston.com' and the temperature '54°F'. The main headline reads: 'Divorce deception: Man forges wife's name on divorce papers, police say'. Below the headline, a short summary states: 'A Houston man now has to answer to his wife and the courts. Harris County Precinct 4 deputies said Paul Nixon, 51, tried to deceive the Harris County District Clerk's office by forging his wife's signature on divorce papers.' The article is attributed to 'Taisha Walker, Reporter' and published on 'September 18, 2019, 6:57 pm'. It includes a newsletter sign-up form.

<https://www.click2houston.com/news/2019/09/18/divorce-deception-man-forges-wifes-name-on-divorce-papers-police-say/>

# Biometric System Attacks

## Obfuscation

When the attacker tries to hide or modify their trait.

Possible solution: use more than one trait (Multibiometrics).



The Daily Dot

Debug IRL

## Is this wearable face projector being used by Hong Kong protesters?

A 2017 'Black Mirror'-esque art project gains a second life on social media.

Mikael Thalen— 2019-10-06 01:33 pm



[https://www.youtube.com/watch?v=\\_PoudPCevN0](https://www.youtube.com/watch?v=_PoudPCevN0)

<https://www.dailyd.com/debug/wearable-face-projector-hong-kong-protesters/>

# Biometric System Attacks

## Spoofing

When the attacker presents to the system a forged non-live trait.  
Possible solution: detect trait liveness.

The screenshot shows the BBC News homepage with a red banner at the top. Below it, a news article is displayed with the title "Doctor 'used silicone fingers' to sign in for colleagues". The article includes a timestamp of "12 March 2013" and social media sharing icons for Facebook, Twitter, and Email.

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



A Brazilian doctor faces charges of fraud after being caught on camera using silicone fingers to sign in for work for absent colleagues, police say.



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# Biometric System Attacks

## Spoofing

When the attacker presents to the system a forged non-live trait.  
*What can we do?*



The BBC News website interface is shown. The top navigation bar includes the BBC logo, a sign-in button, and links for News, Sport, Reel, Worklife, Travel, Future, and more. Below this is a large red 'NEWS' banner. The main menu below the banner includes Home, Video, World, US & Canada, UK, Business, Tech, Science, Stories, and Entertainment. Under the World section, links for Africa, Asia, Australia, Europe, Latin America, and Middle East are visible. The main article headline reads "Doctor 'used silicone fingers' to sign in for colleagues". Below the headline is a timestamp "© 12 March 2013" and social sharing icons for Facebook, Twitter, Email, and a "Share" button.

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



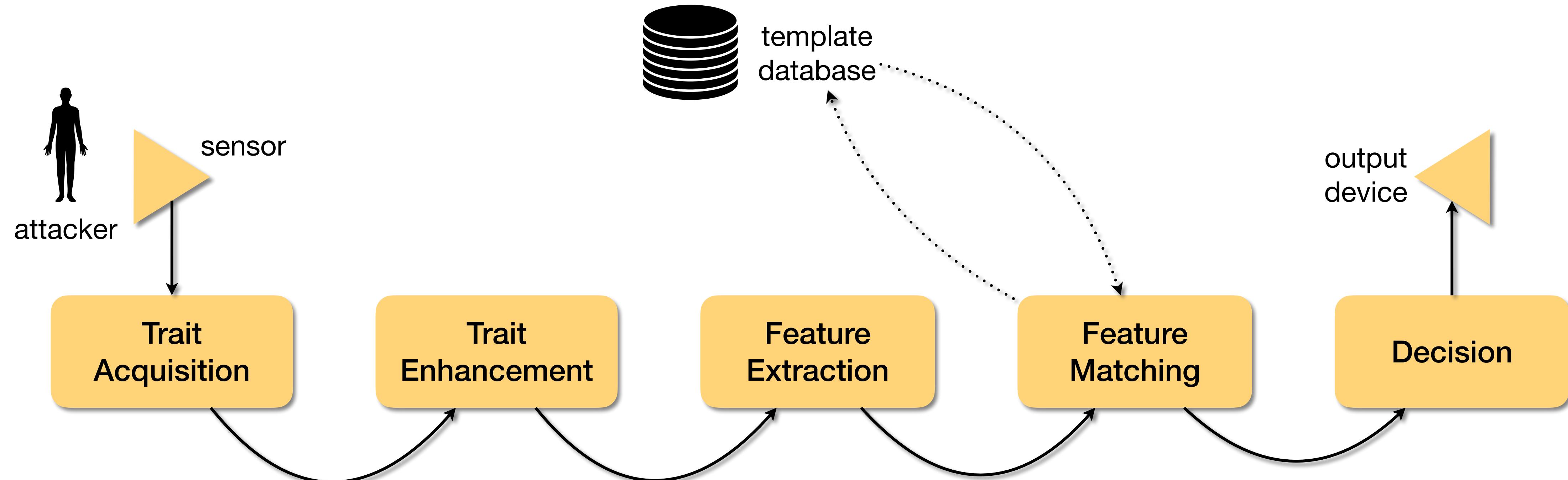
A Brazilian doctor faces charges of fraud after being caught on camera using silicone fingers to sign in for work for absent colleagues, police say.



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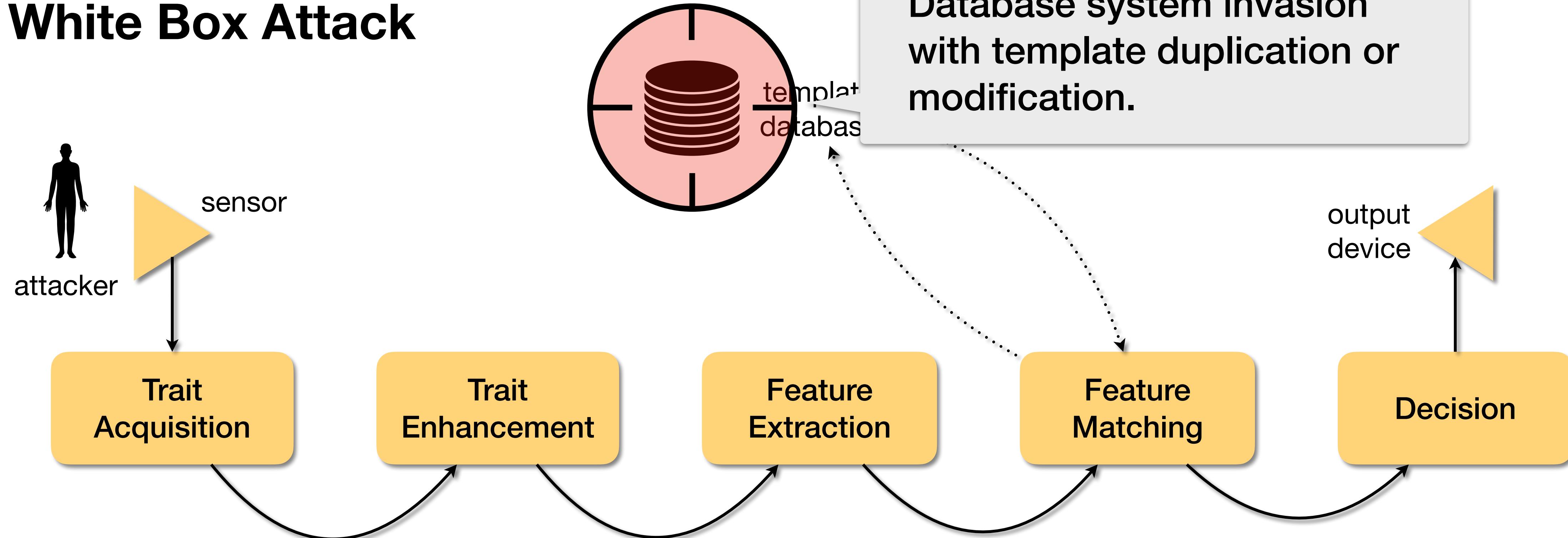
# Biometric System Attacks

## White Box Attack



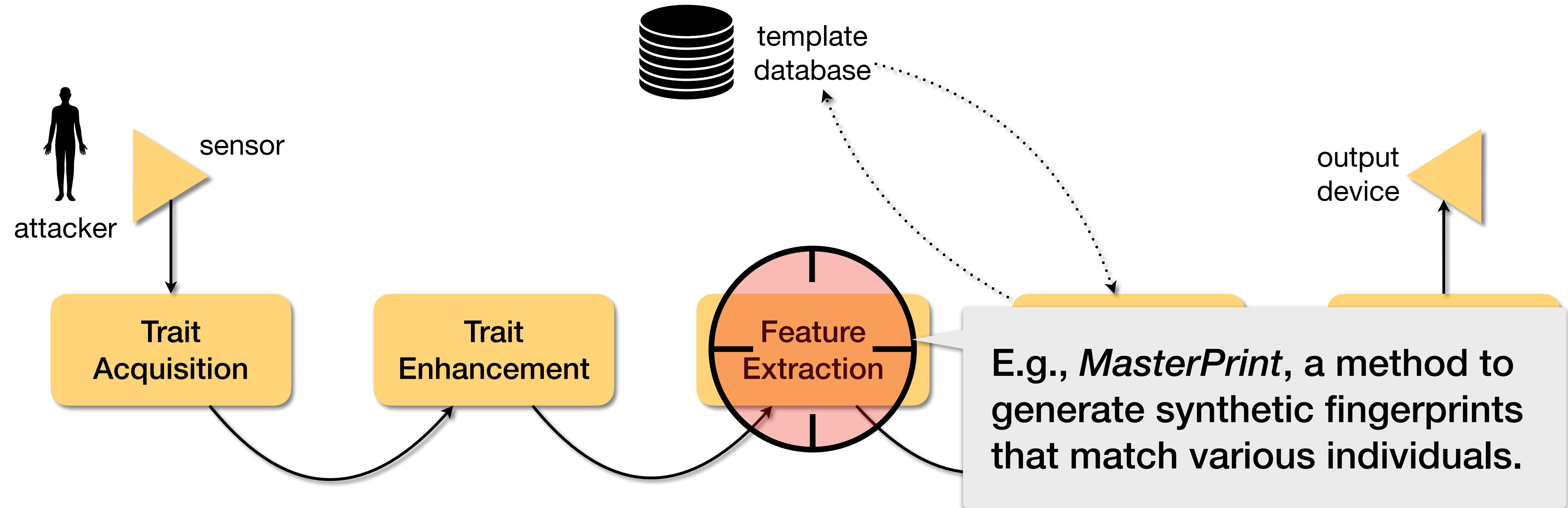
# Biometric System Attacks

## White Box Attack



# Biometric System Attacks

## White Box Attack



# Biometric System Attacks

## MasterPrint

IEEE TRANSACTIONS ON INFORMATION FORENSICS AND SECURITY, VOL. 12, NO. 9, SEPTEMBER 2017

2013

### MasterPrint: Exploring the Vulnerability of Partial Fingerprint-Based Authentication Systems

Aditi Roy, *Student Member, IEEE*, Nasir Memon, *Fellow, IEEE*, and Arun Ross, *Senior Member, IEEE*

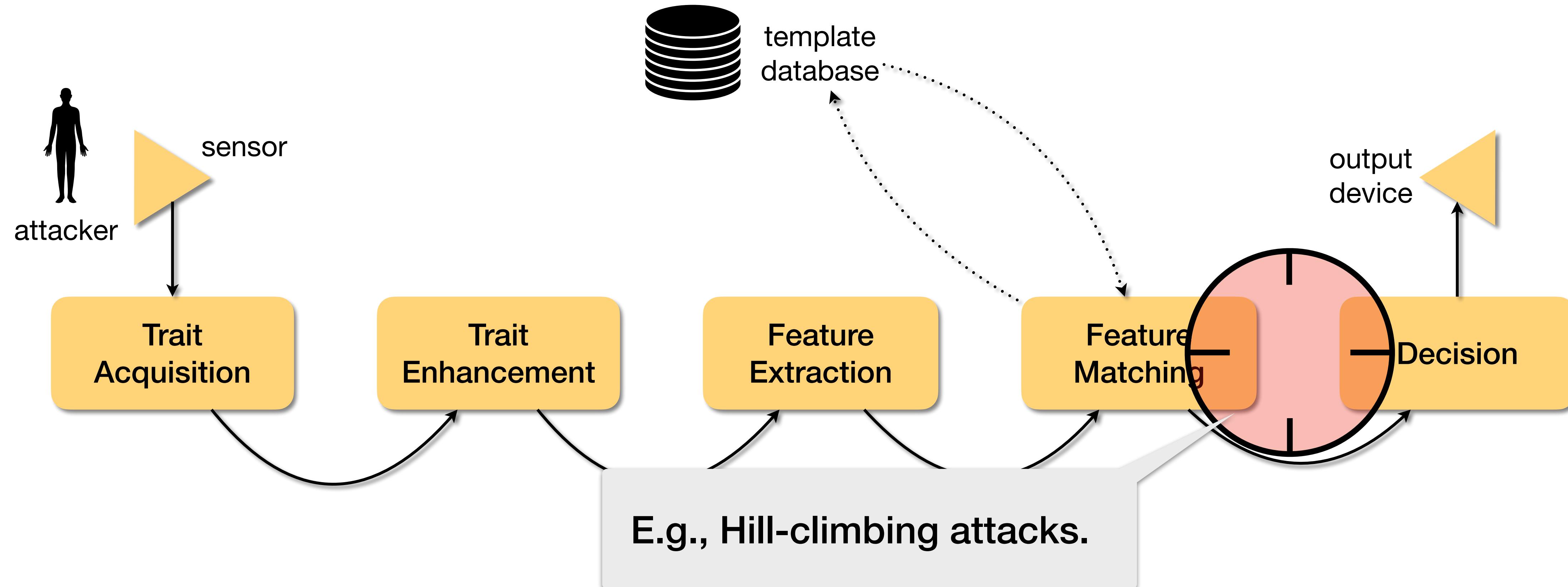


[https://www.cse.msu.edu/~rossarun/pubs/  
RoyMemonRossMasterPrint\\_TIFS2017.pdf](https://www.cse.msu.edu/~rossarun/pubs/RoyMemonRossMasterPrint_TIFS2017.pdf)

templates. This paper investigates the possibility of generating a “MasterPrint,” a synthetic or real partial fingerprint that serendipitously matches one or more of the stored templates for a significant number of users. Our preliminary results on an

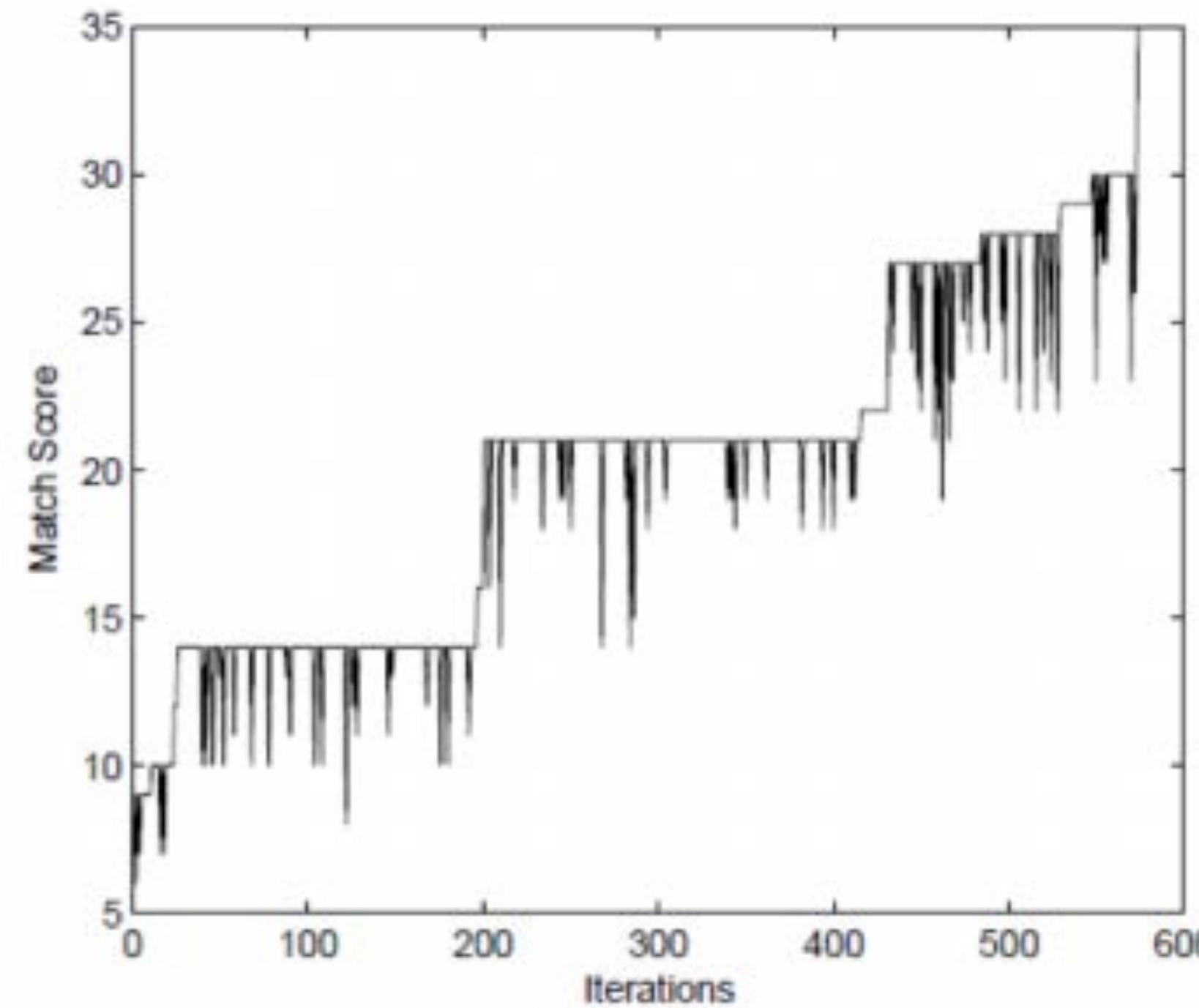
# Biometric System Attacks

## White Box Attack



# Biometric System Attacks

## Hill-climbing Attack E.g. Fingerprints

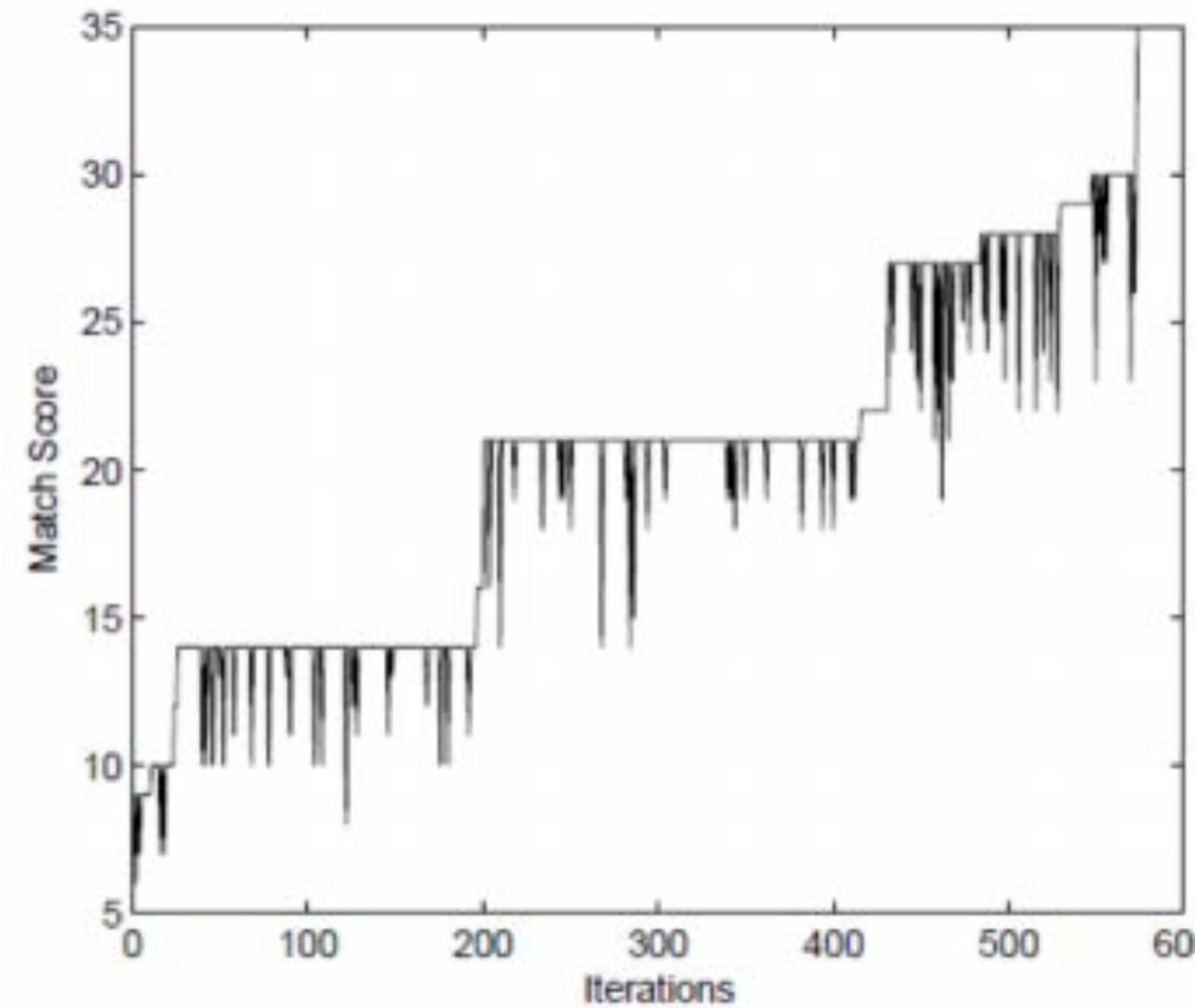


The attacker iteratively provides synthetic trait samples to the system. At each iteration, the attacker observes how the similarity scores are progressing.

Martinez-Diaz et al.  
*Hill-Climbing and Brute-Force Attacks on Biometric Systems: A Case Study in Match-on-Card Fingerprint Verification*  
IEEE ICCST, 2006

# Biometric System Attacks

## Hill-climbing Attack E.g. Fingerprints



With such progress feedback, the attacker can guide the generation of better and better synthetic fingerprint samples, up the point of trespassing the decision threshold.

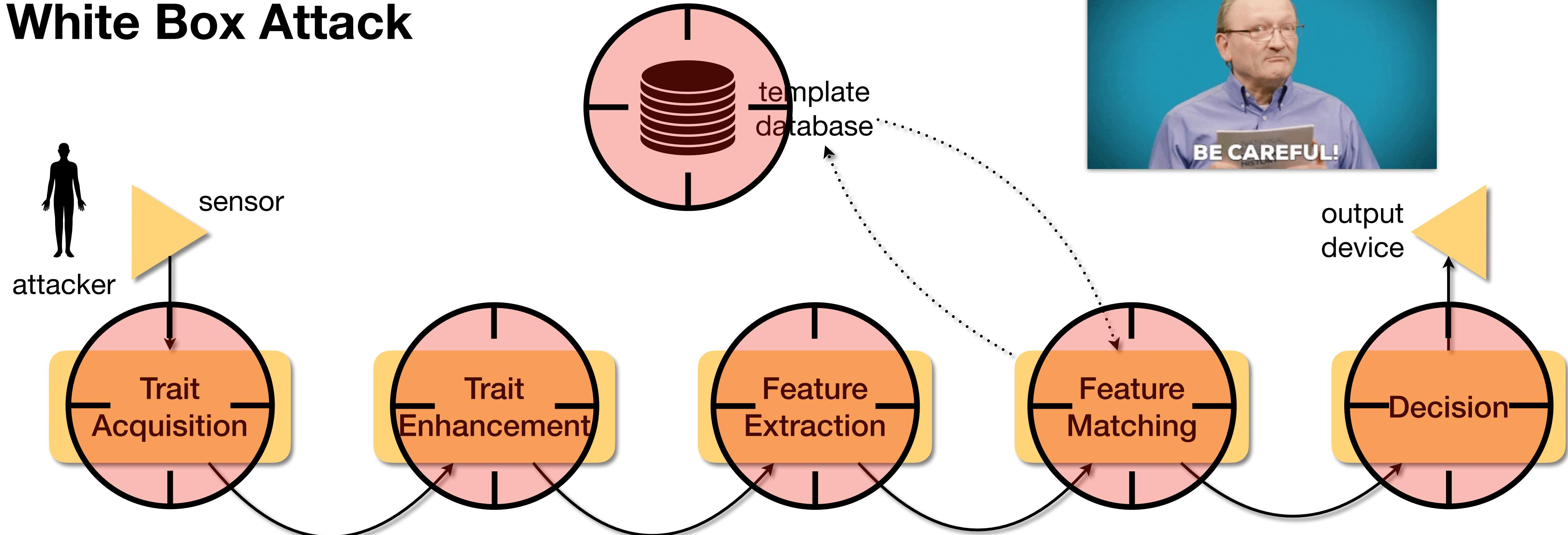
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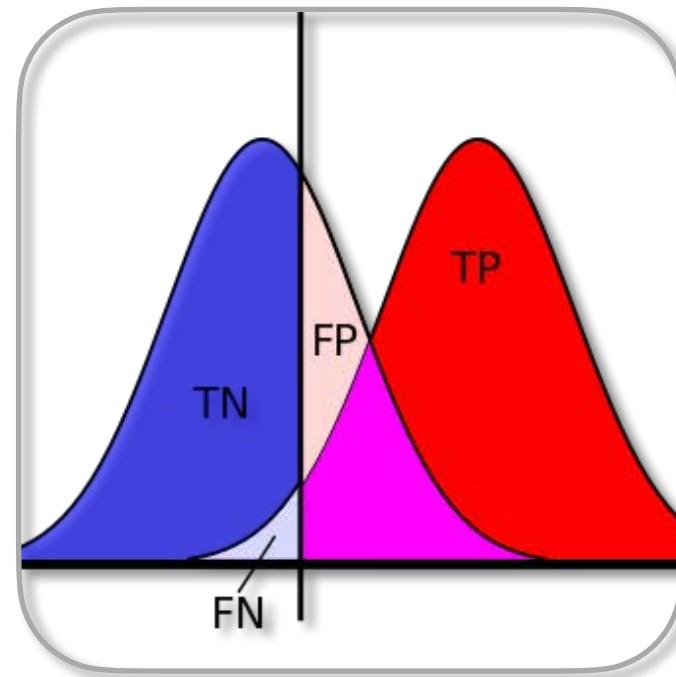
# Biometric System Attacks

## White Box Attack



# Course Overview

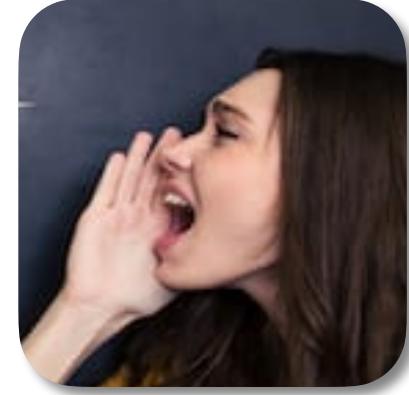
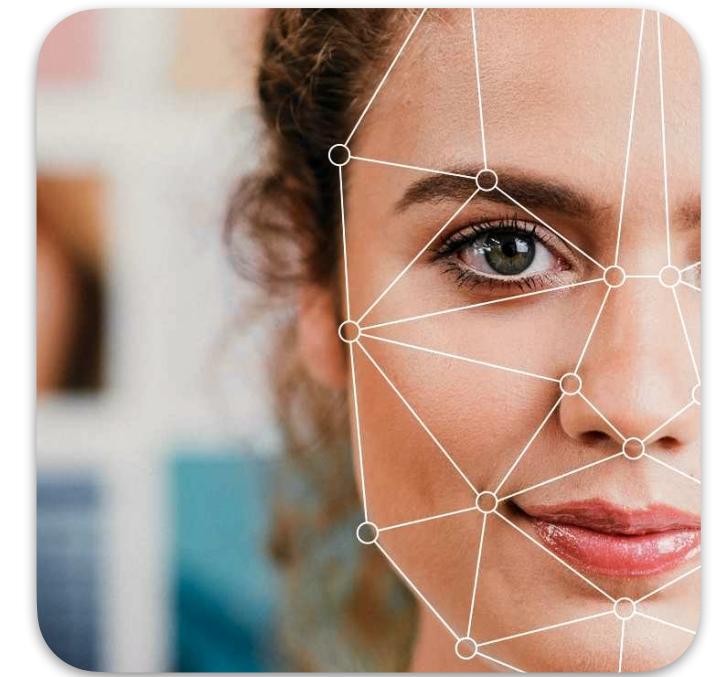
## Content



**Basics**  
Concepts  
Metrics  
Metric implementation



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



**Alternative Traits and Fusion Concepts**



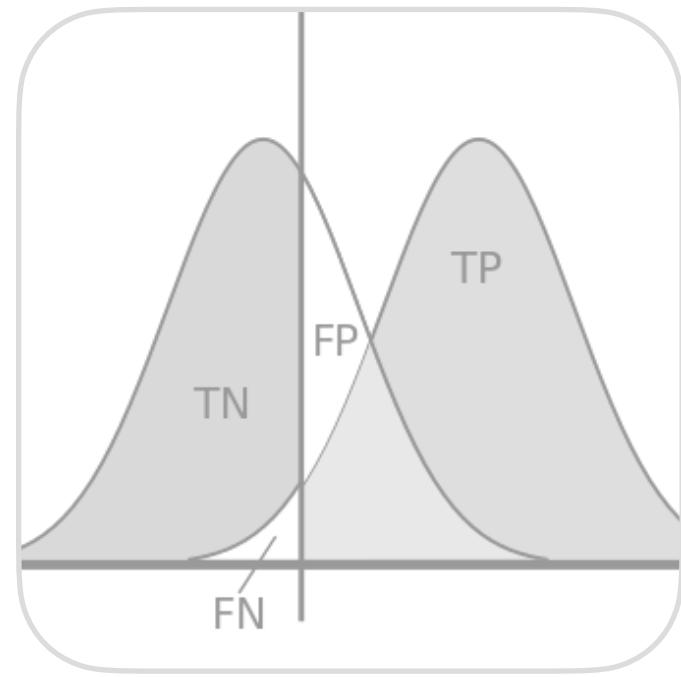
**Invited Talks (2)**  
State of the art  
Future work



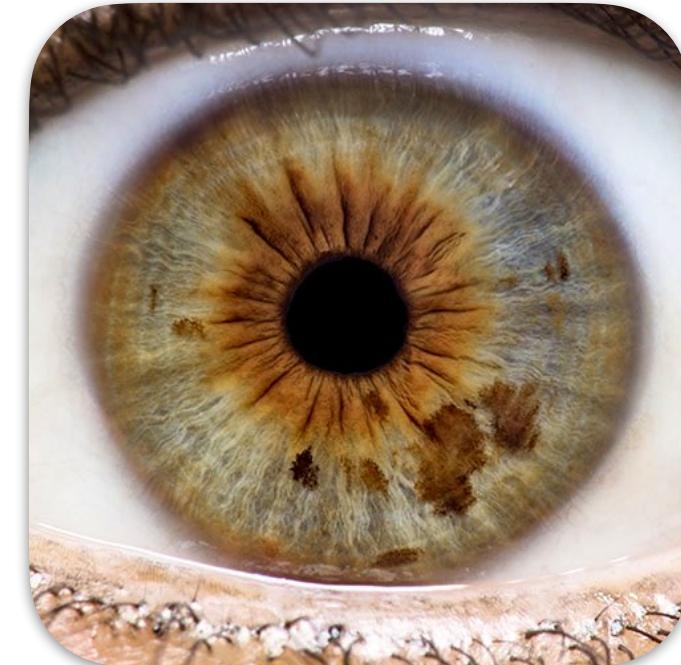
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# Course Overview

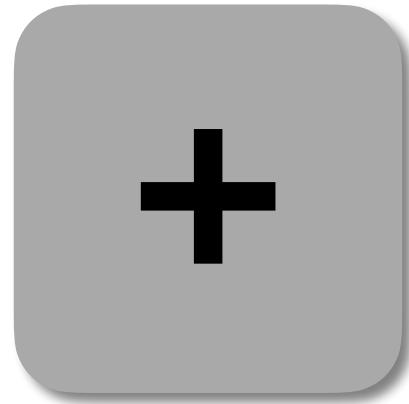
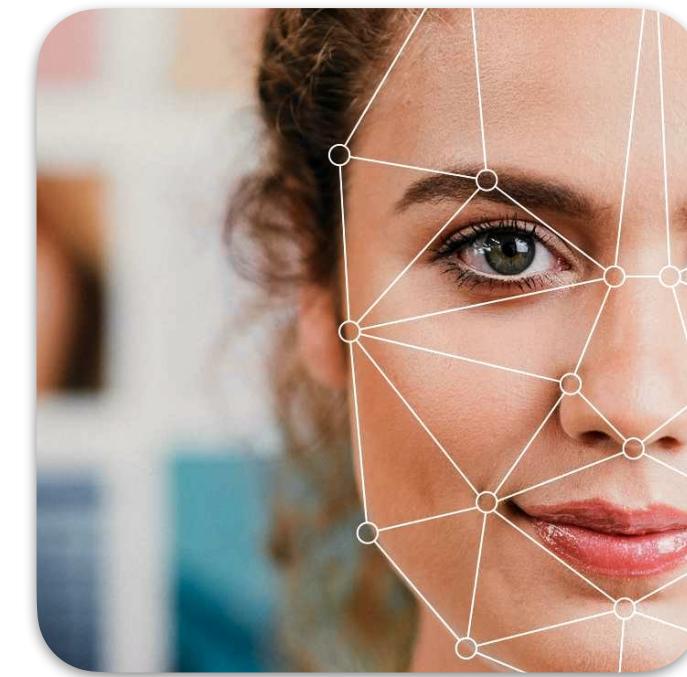
## Content



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



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# History

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

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



# History

## Skin Types



smooth skin



friction ridge

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

# 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.

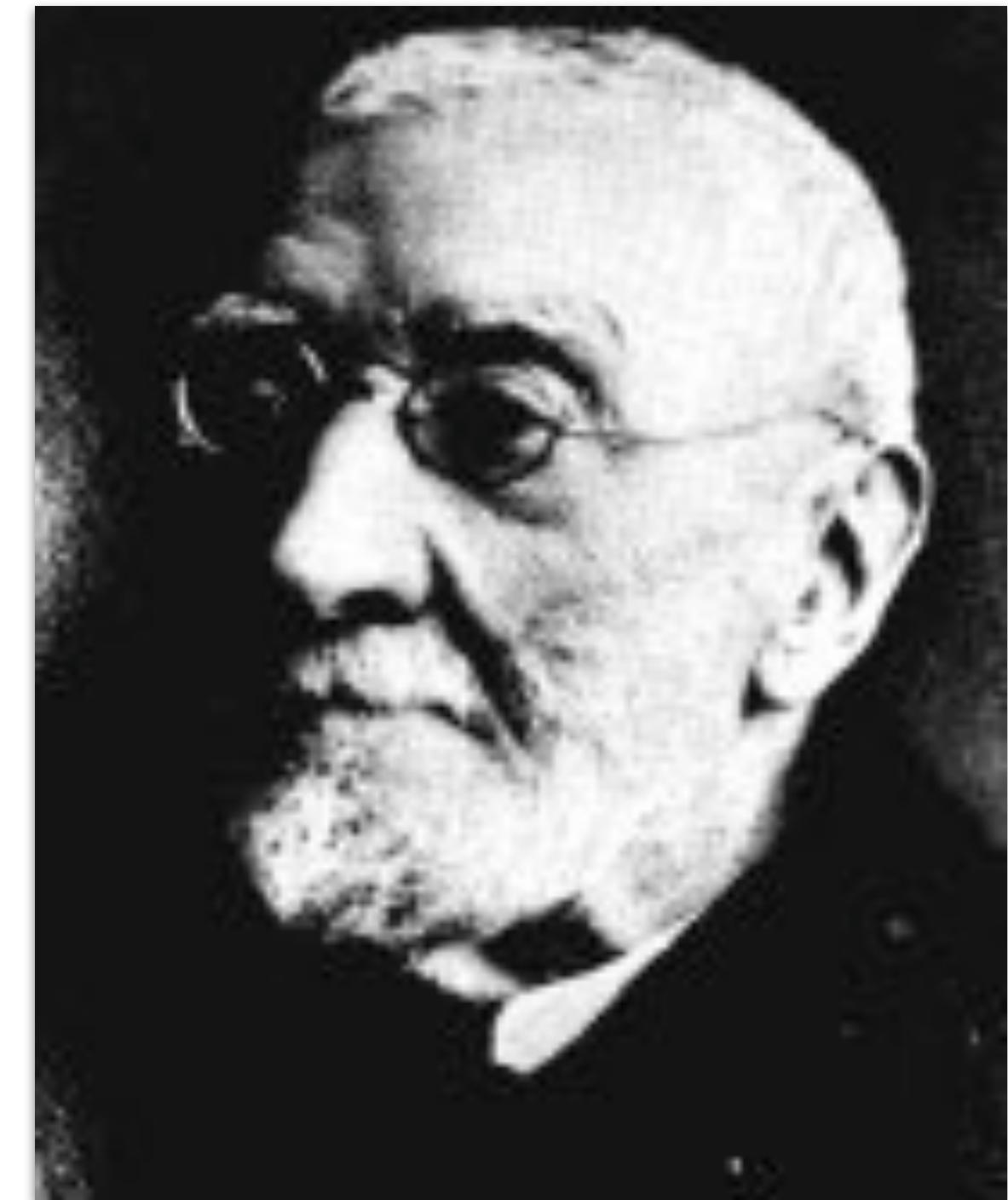


# History

## **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.

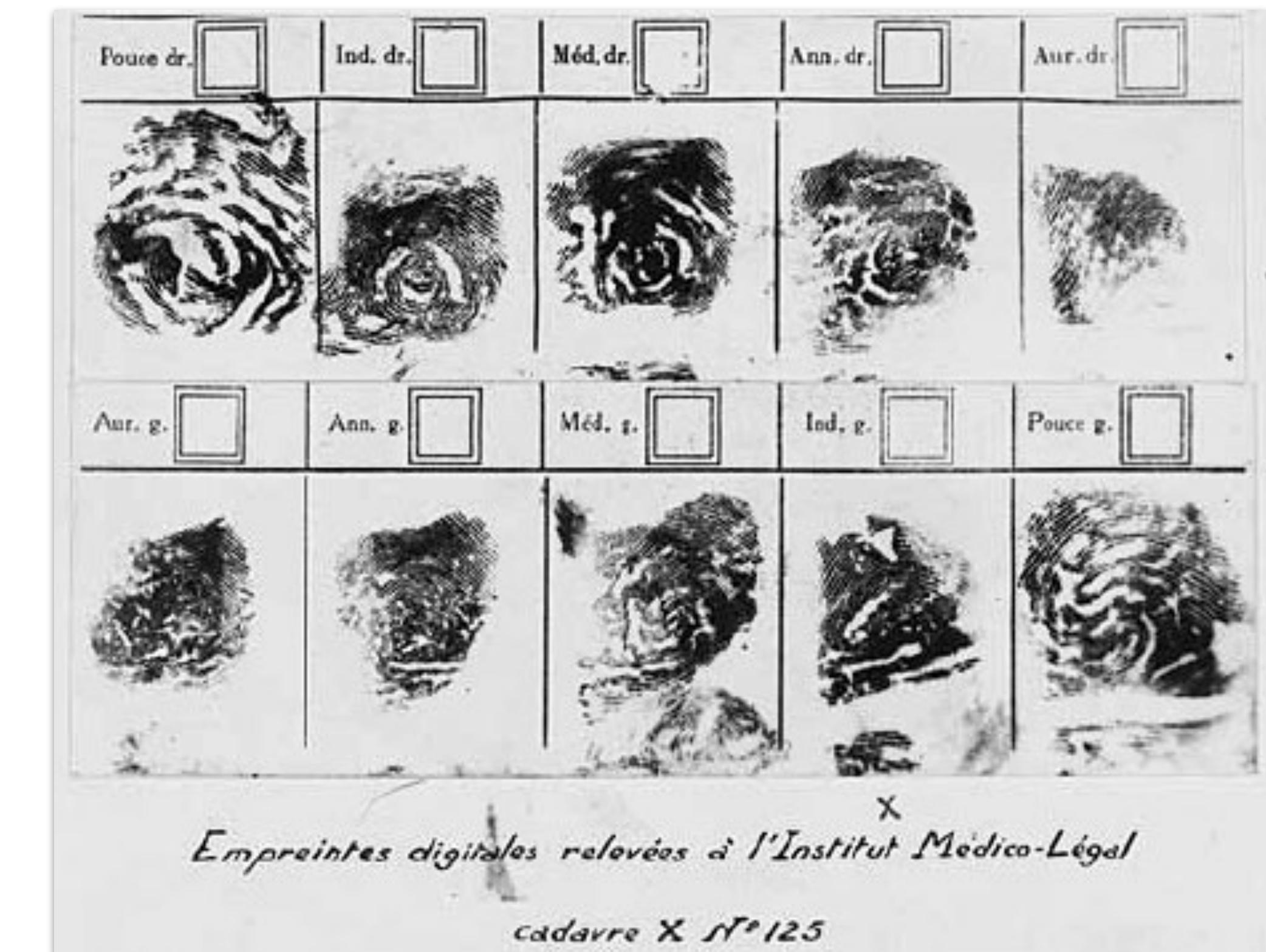


# History

## Henry Faulds (UK, 1880)

Pioneering usage of fingerprints  
in a forensic scenario.

Performed the first experiments  
showing the uniqueness of  
fingerprints.

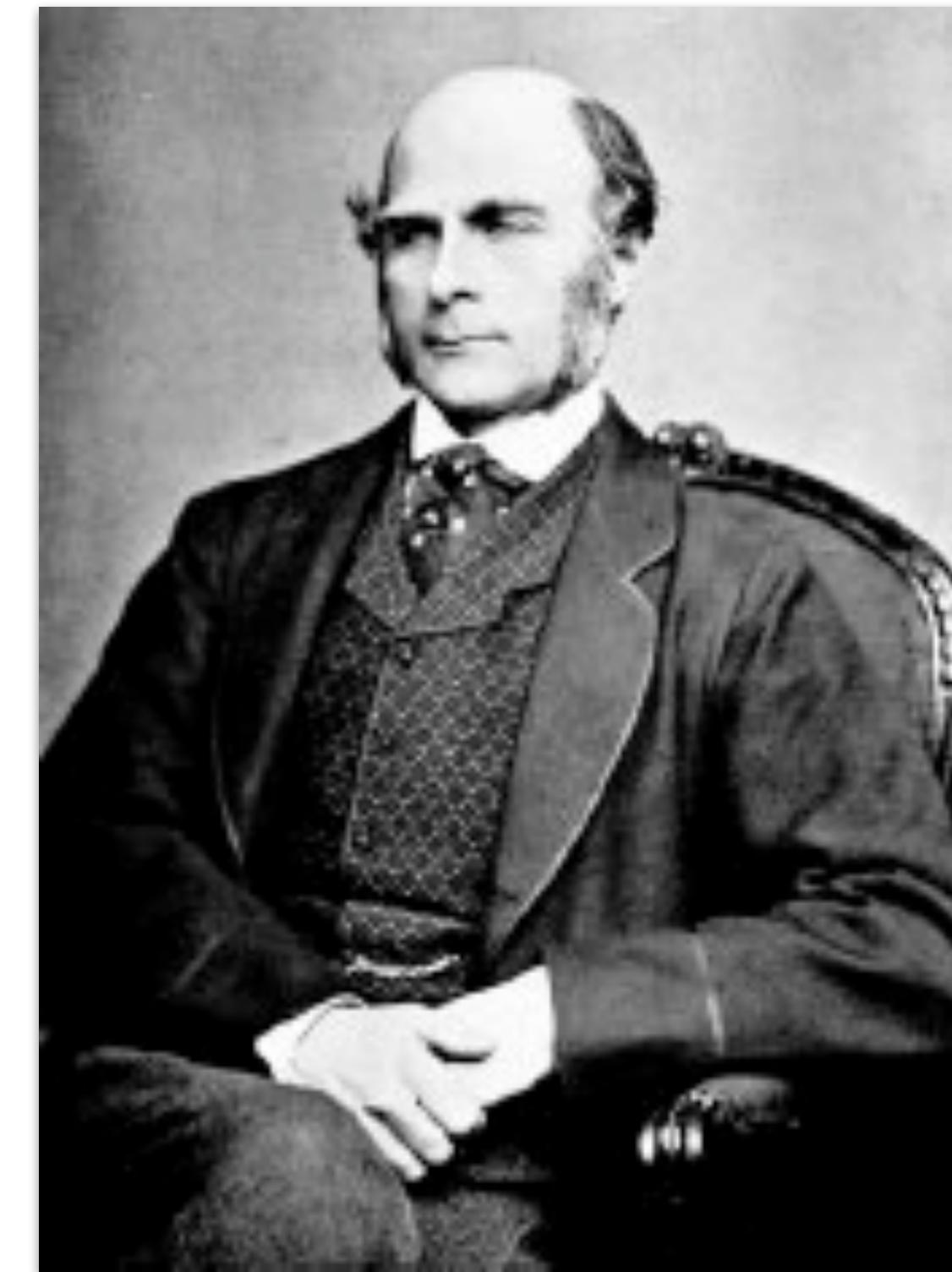


# History

**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



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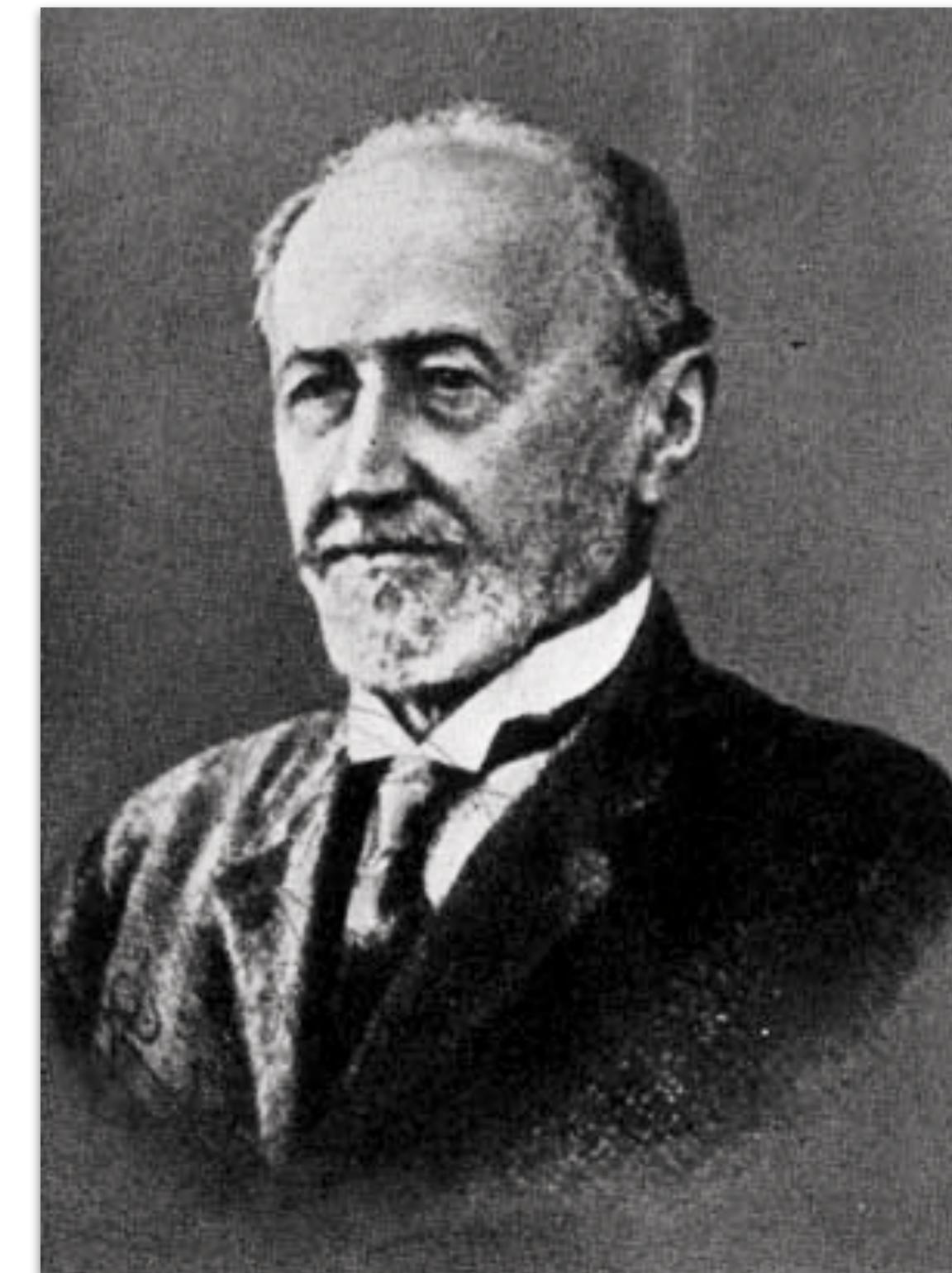
# History

**Juan Vucetich (Argentina, 1892)**

Pioneering criminal conviction based  
on fingerprints.

**Rojas case**

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



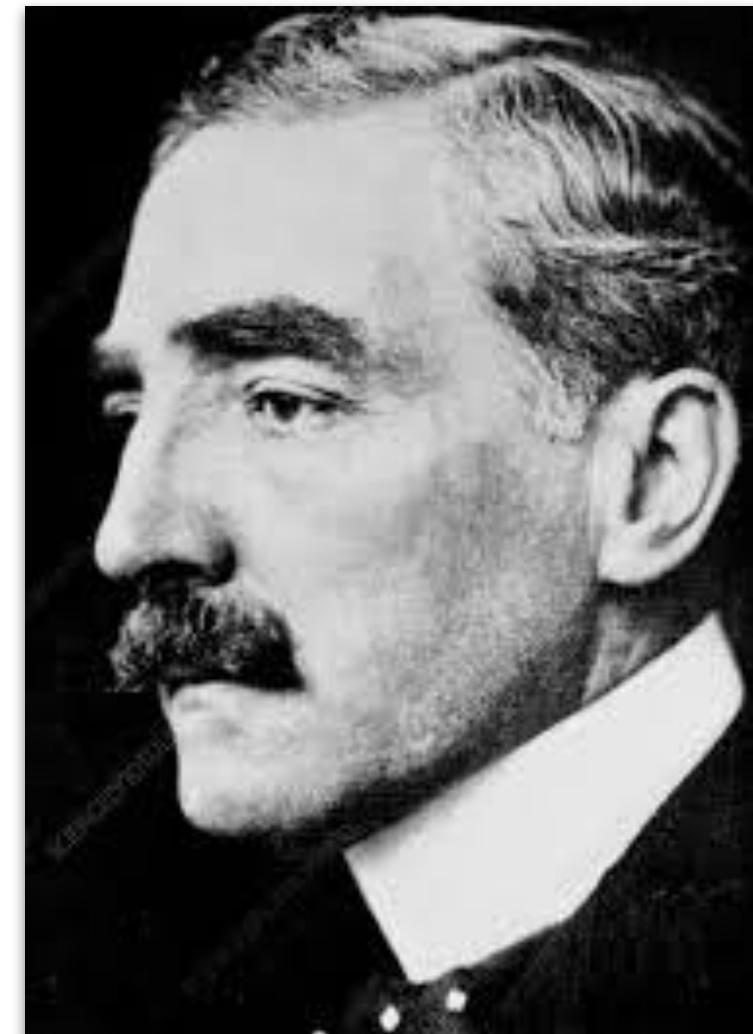
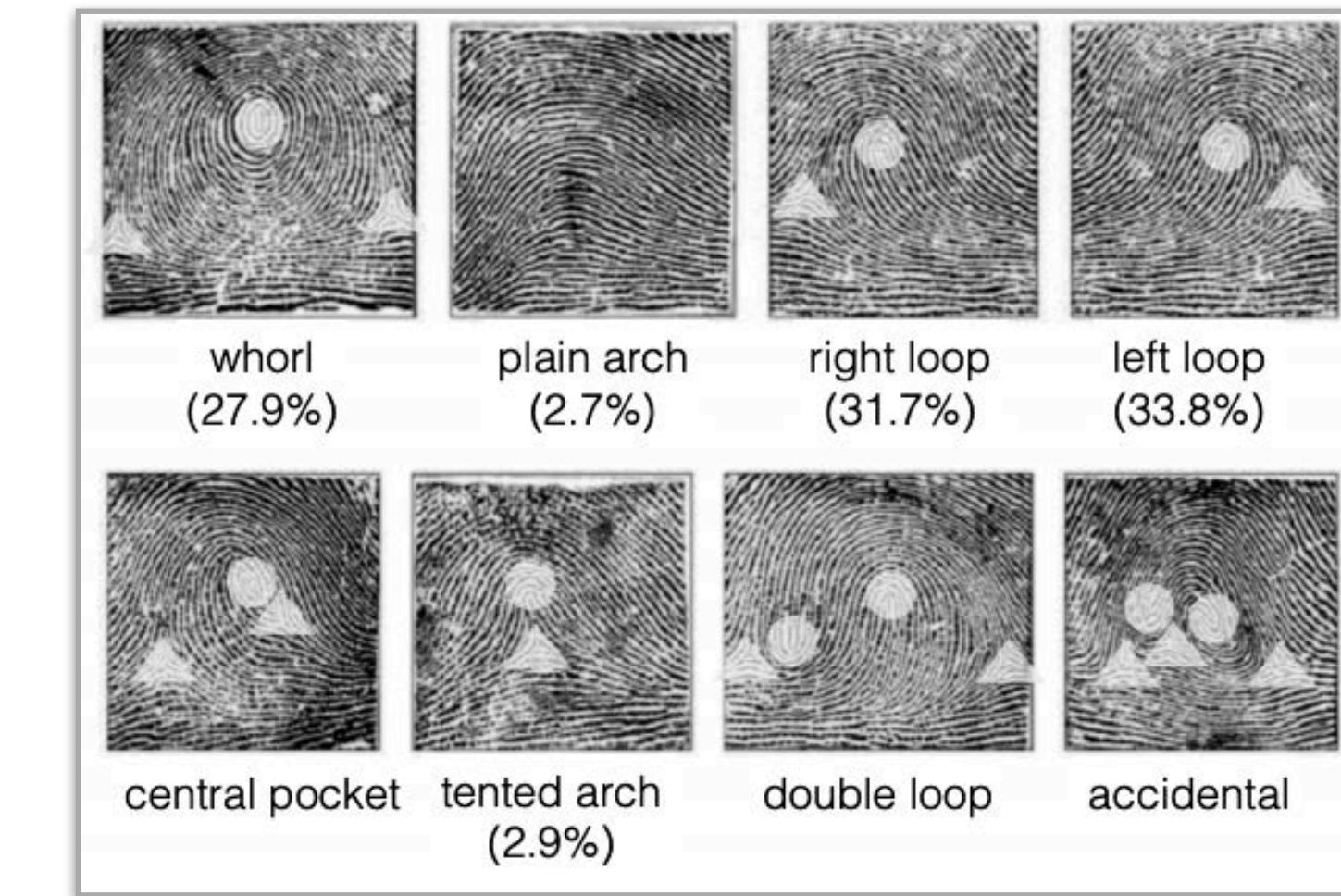
# History

## 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.



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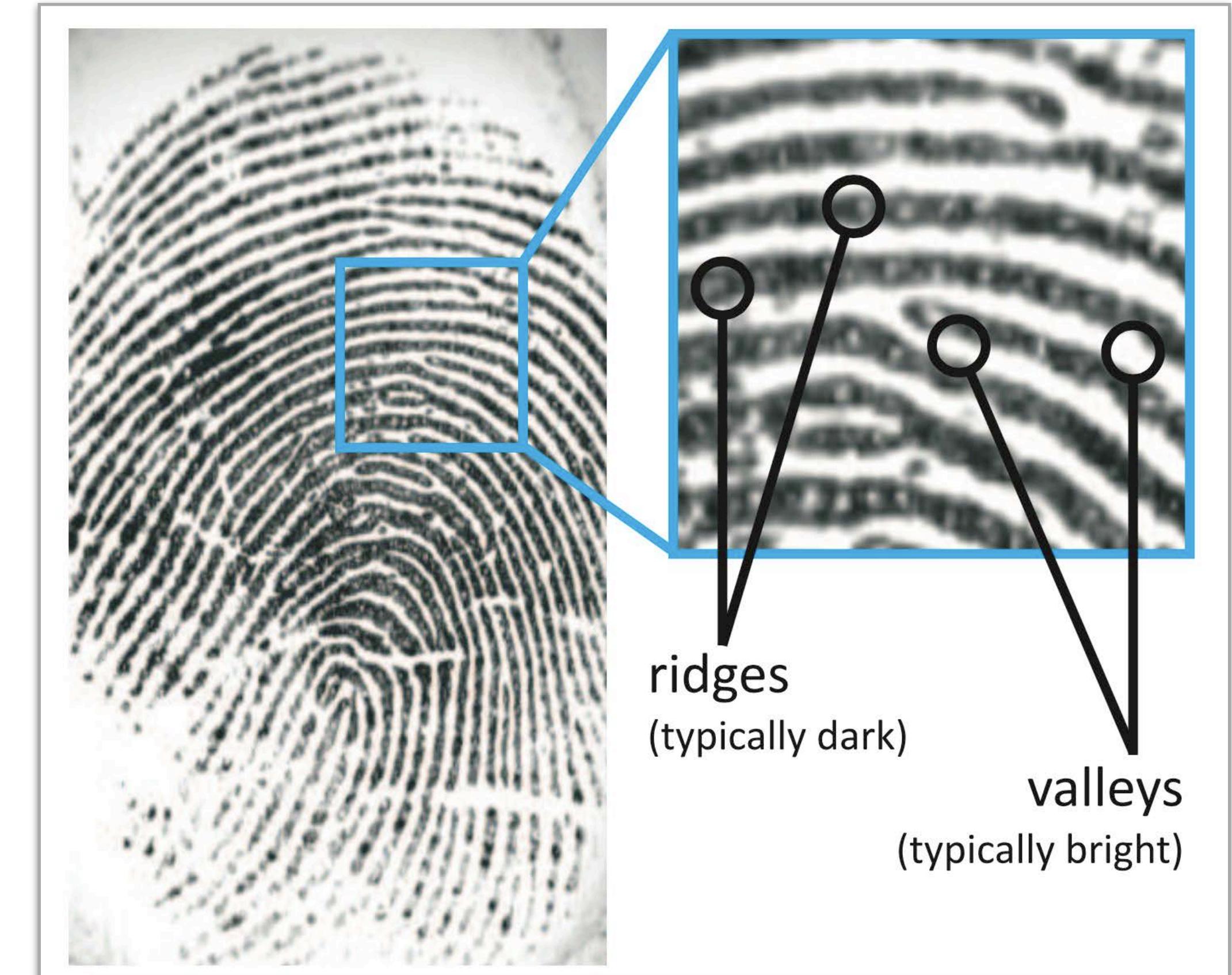
# Features

**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



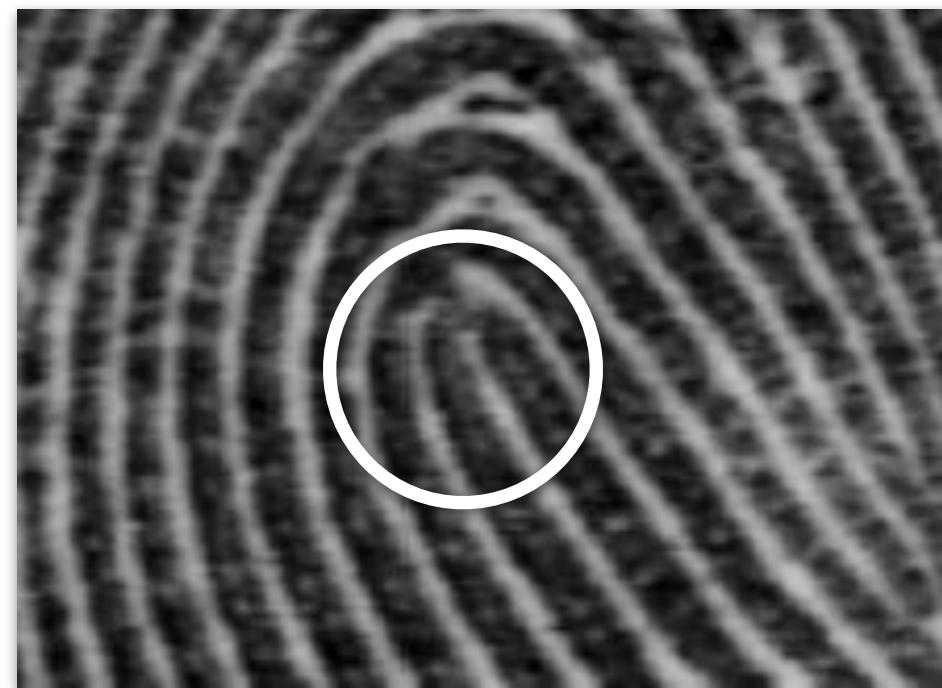
# Features

## Level-1 Features

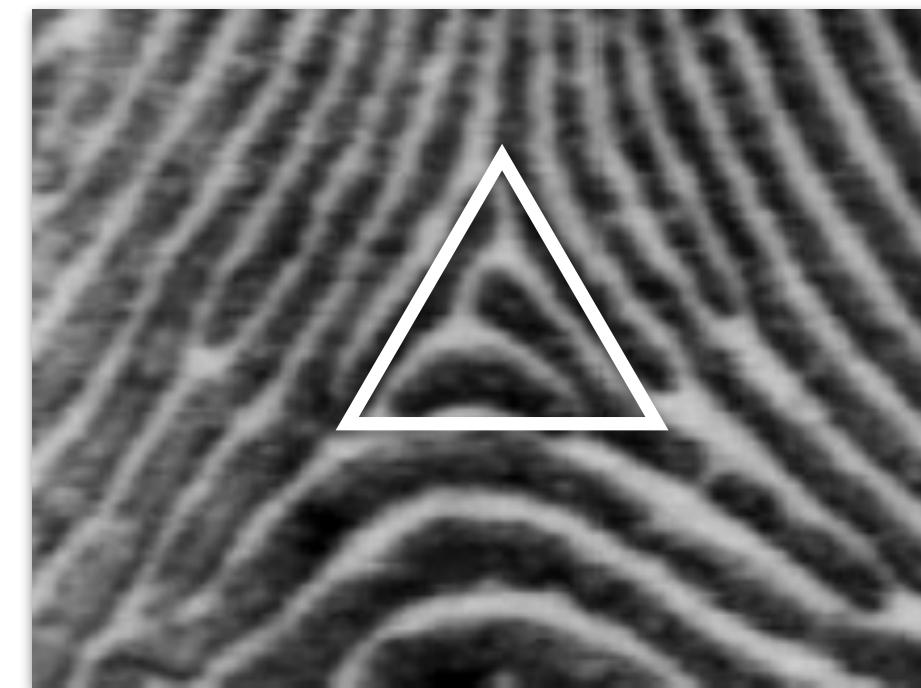
Observe singular points and core.

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)

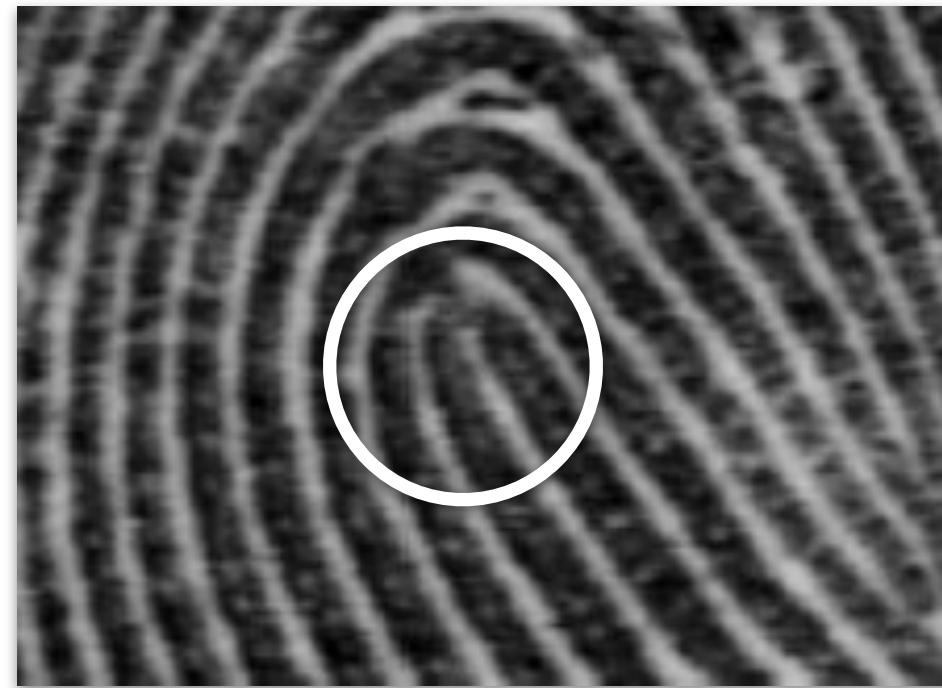
Point of maximum ridge curvature.

# Features

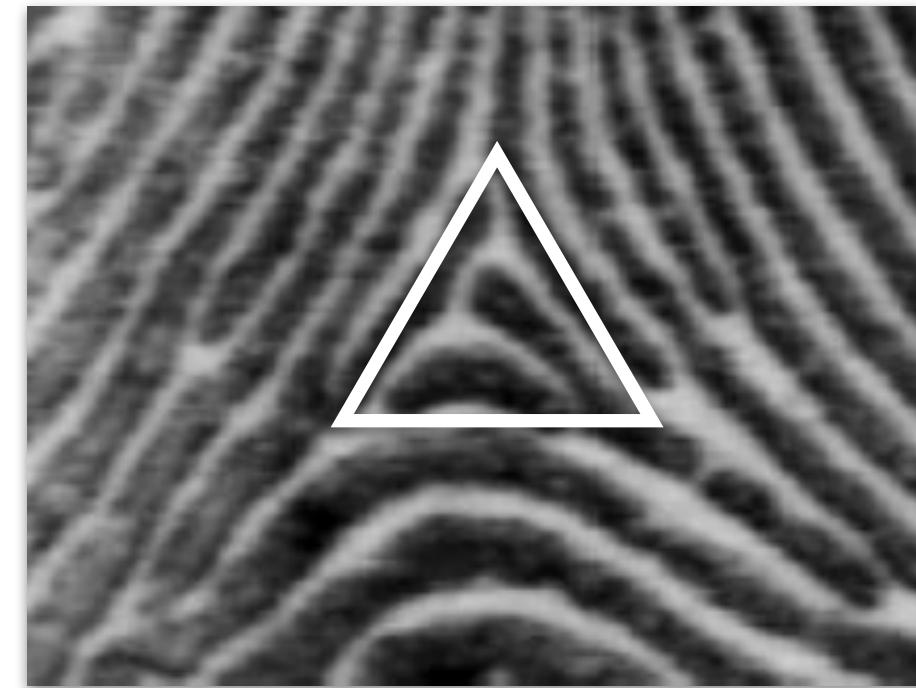
## Level-1 Features

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 Nandakumar  
*Introduction to Biometrics*  
Springer Books, 2011



plain arch  
4%

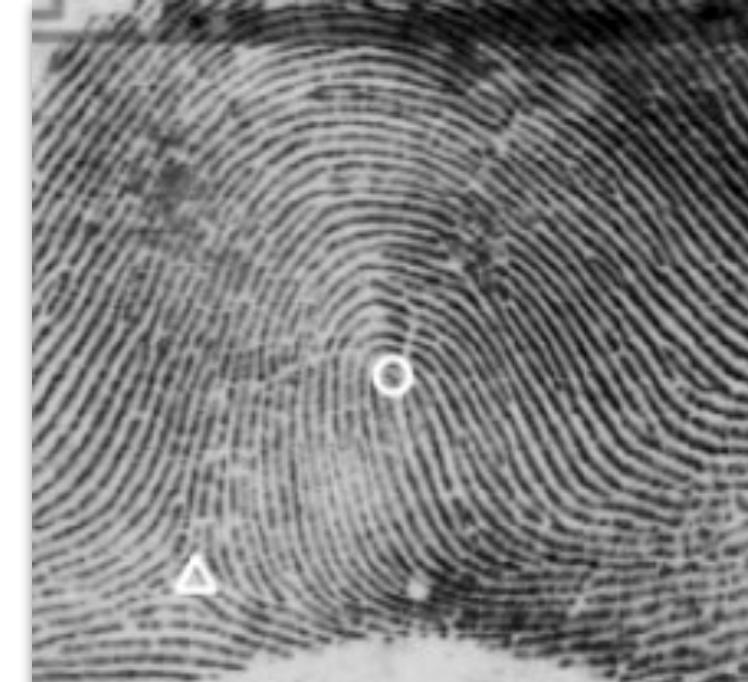


tented arch  
3%



left loop

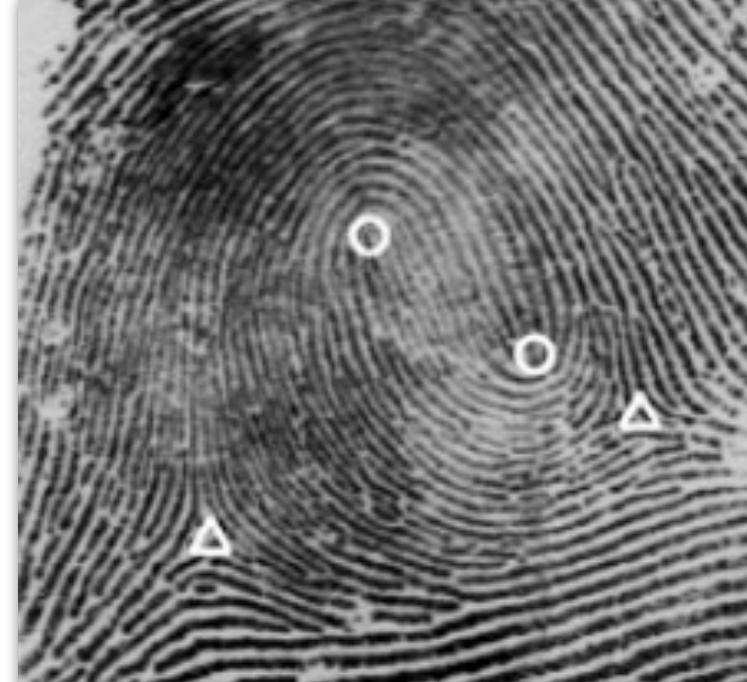
65%



right loop



whorl  
24%



twin loop  
4%

Percentages: frequencies of observation.

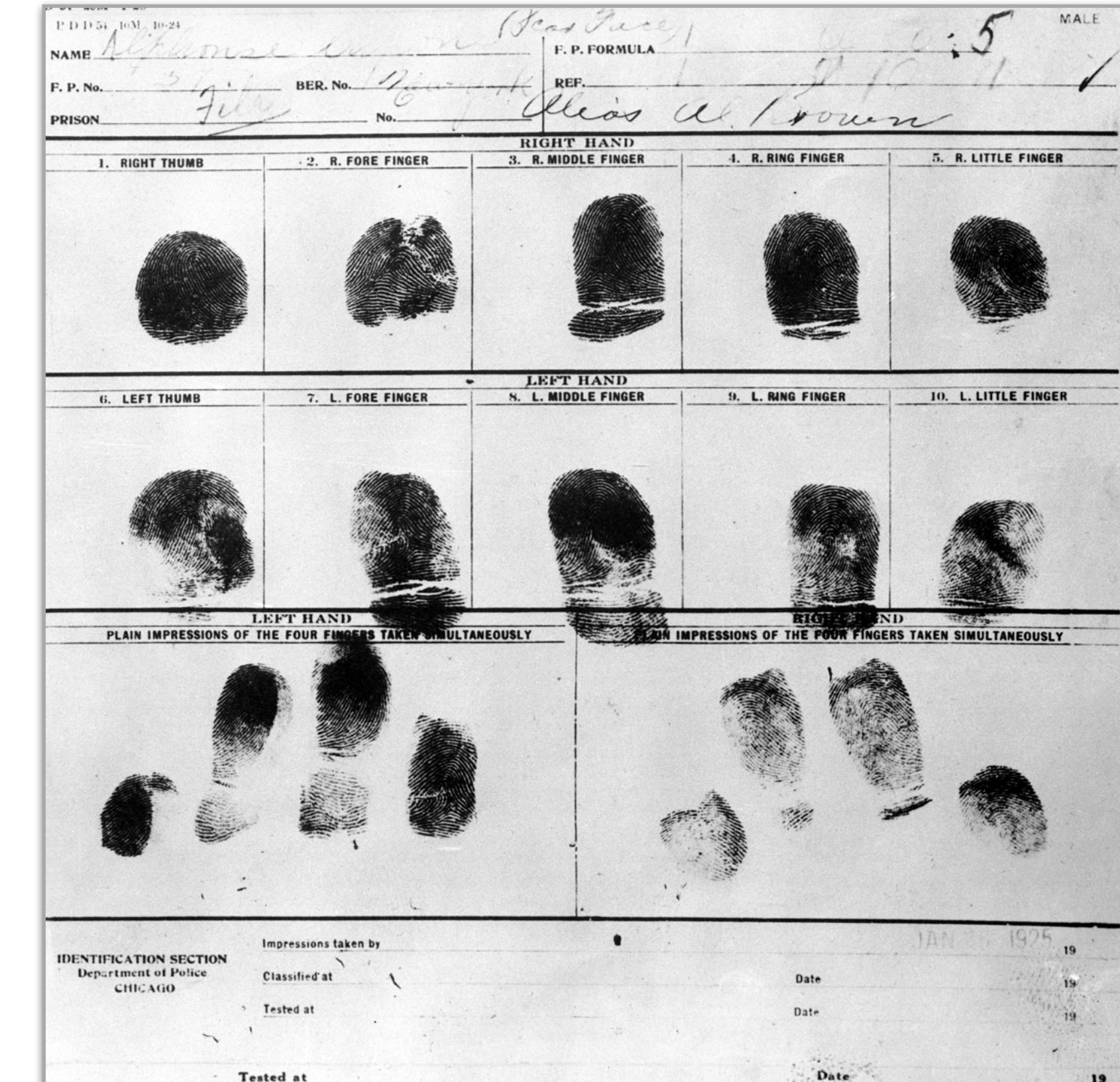
# Features

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.



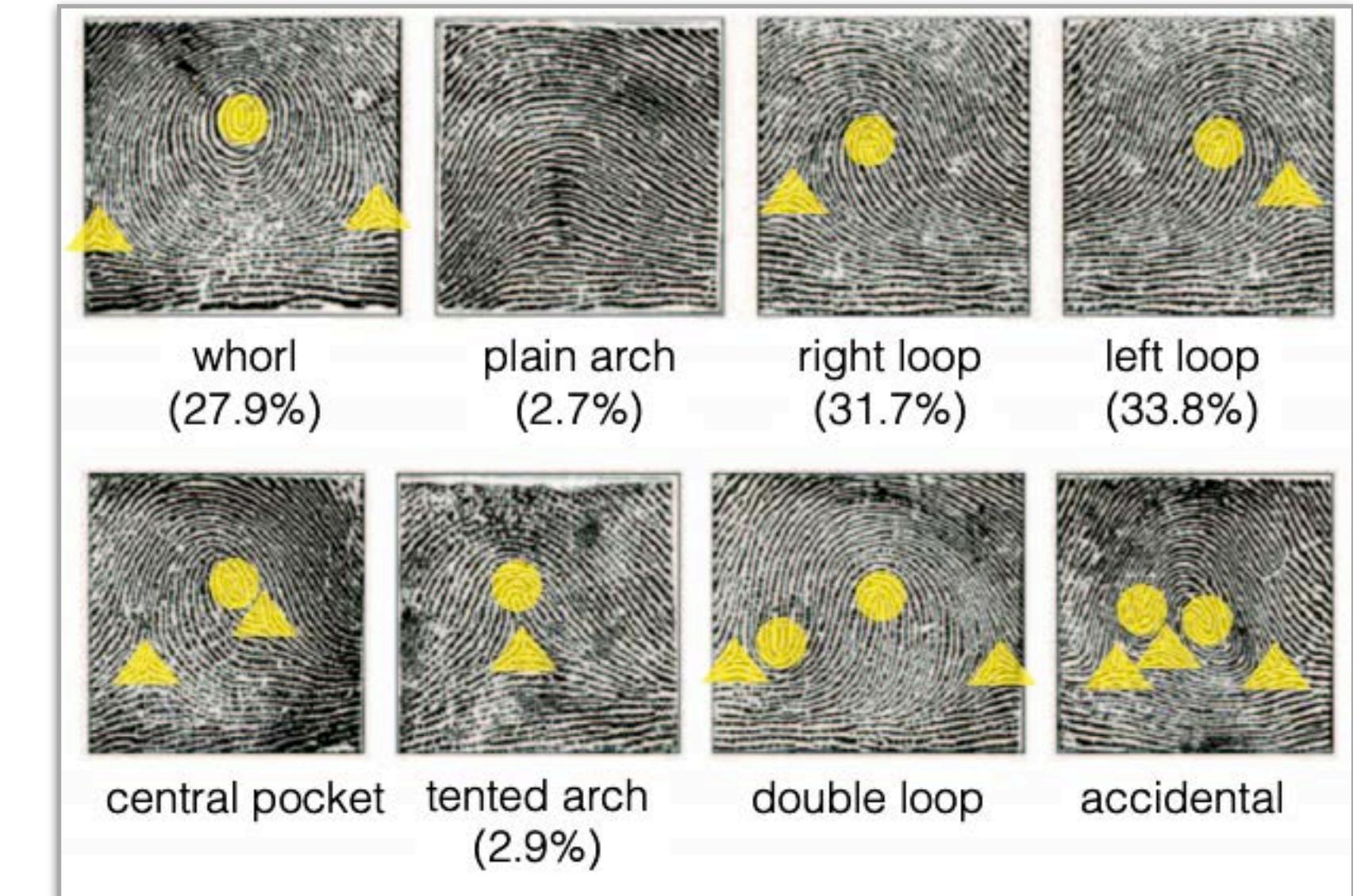
# Features

**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

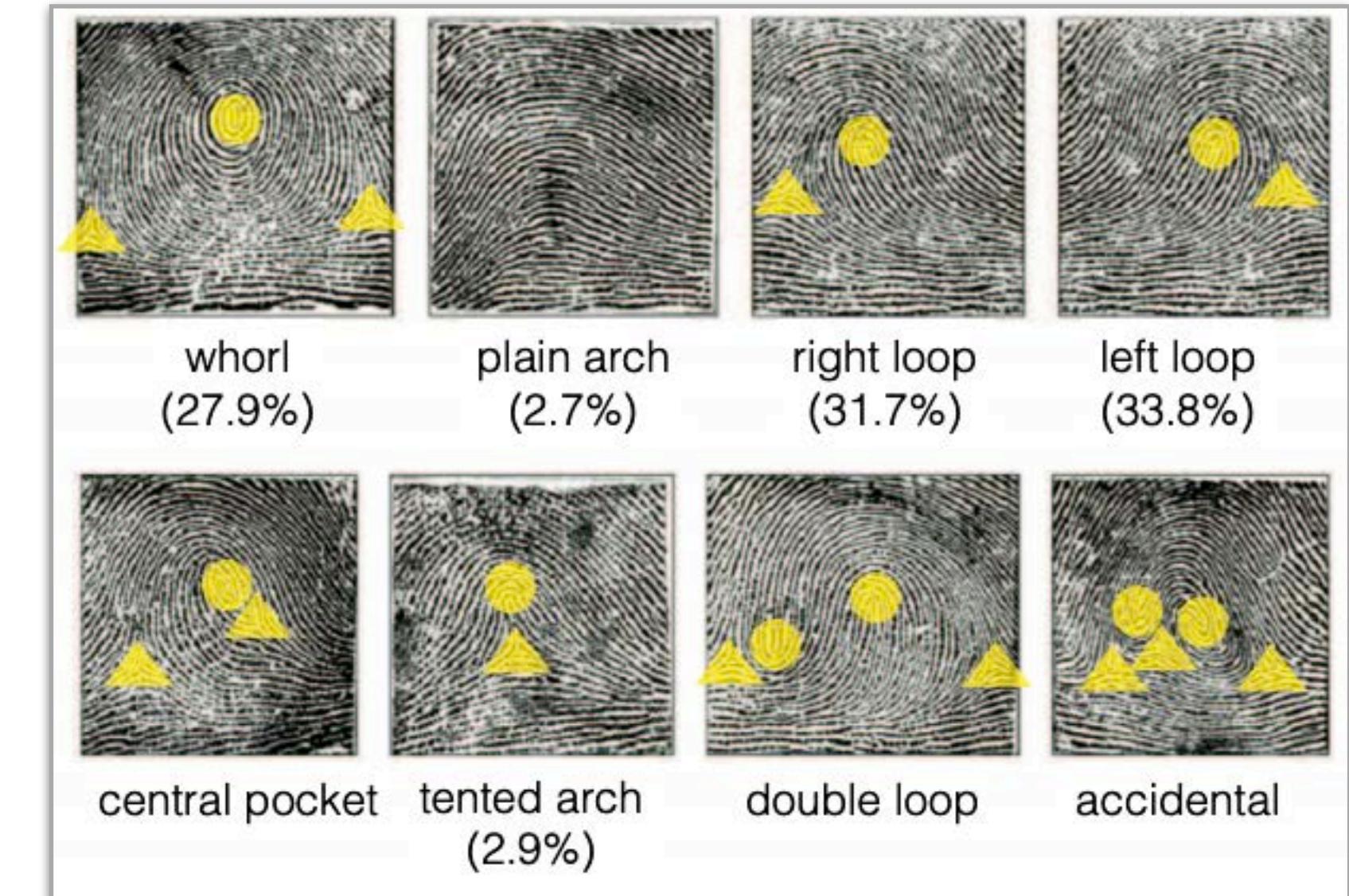
**How useful are level-1 features?**

**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



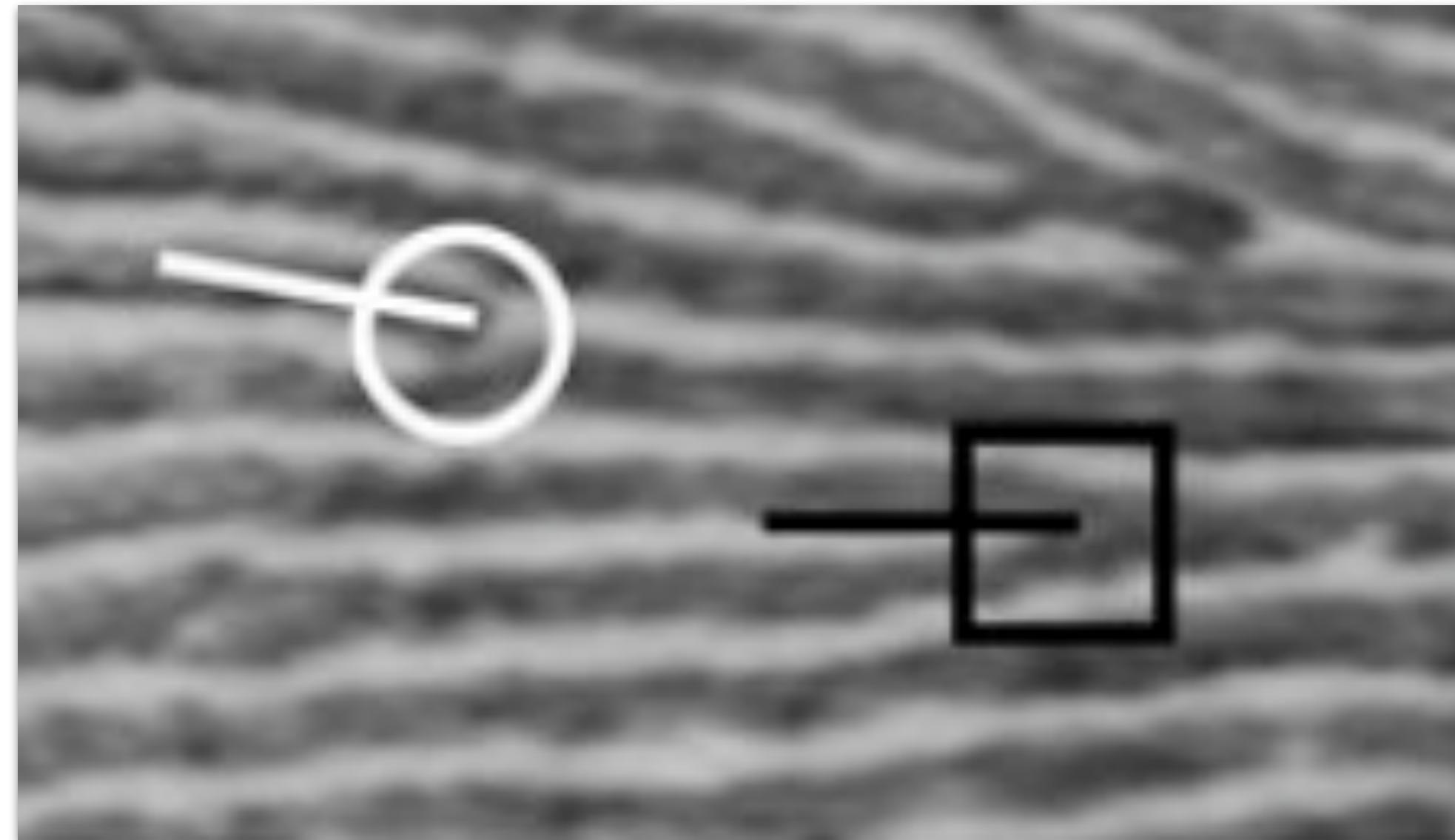
# Features

## Level-2 Features

Observe minutiae (Galton's details).

Useful capture resolution: 500 ppi

Ridge Ending



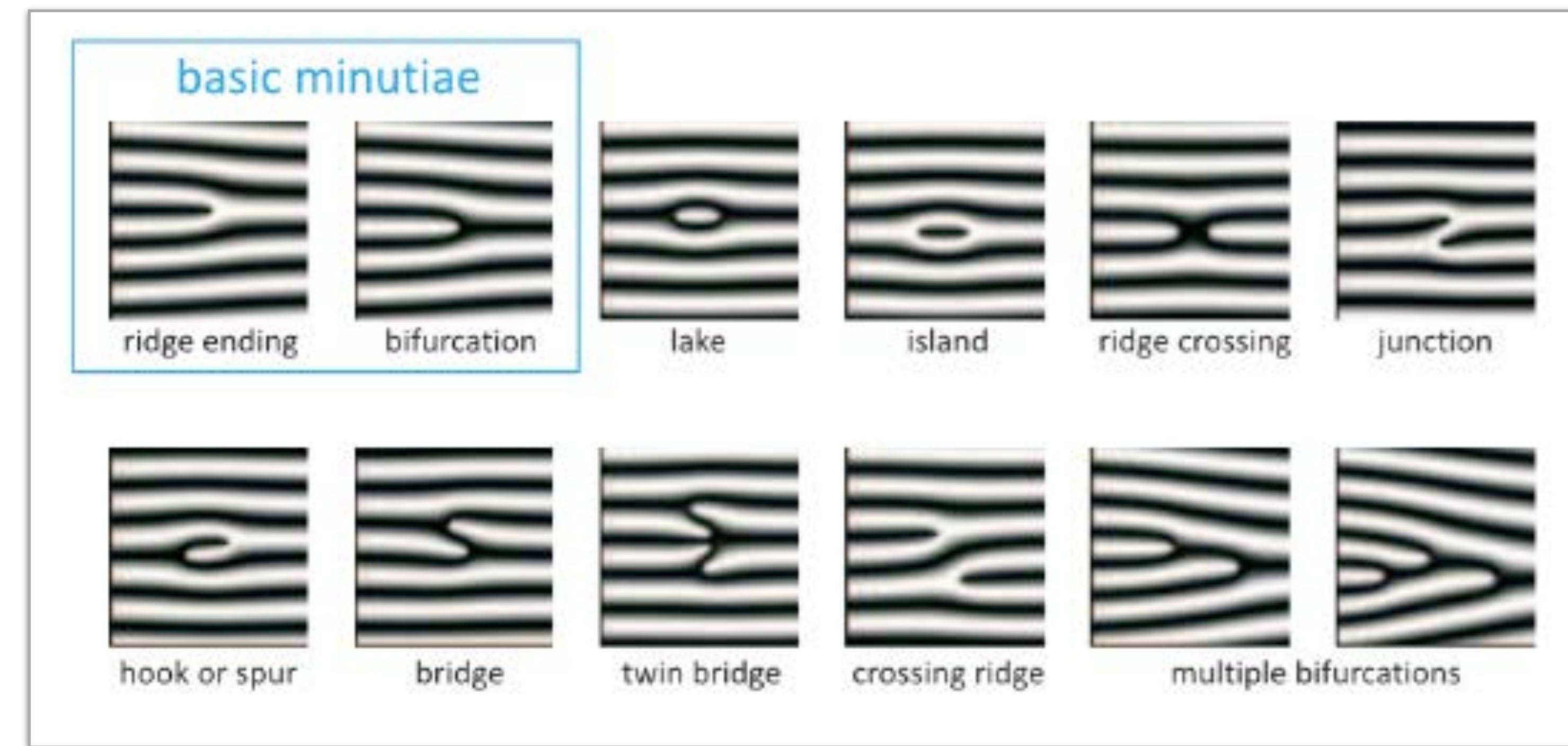
Ridge Bifurcation

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)



**LOYOLA**  
UNIVERSITY CHICAGO

# Features

## Level-2 Features

**Usage of minutiae**  
Fingerprint matching.

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

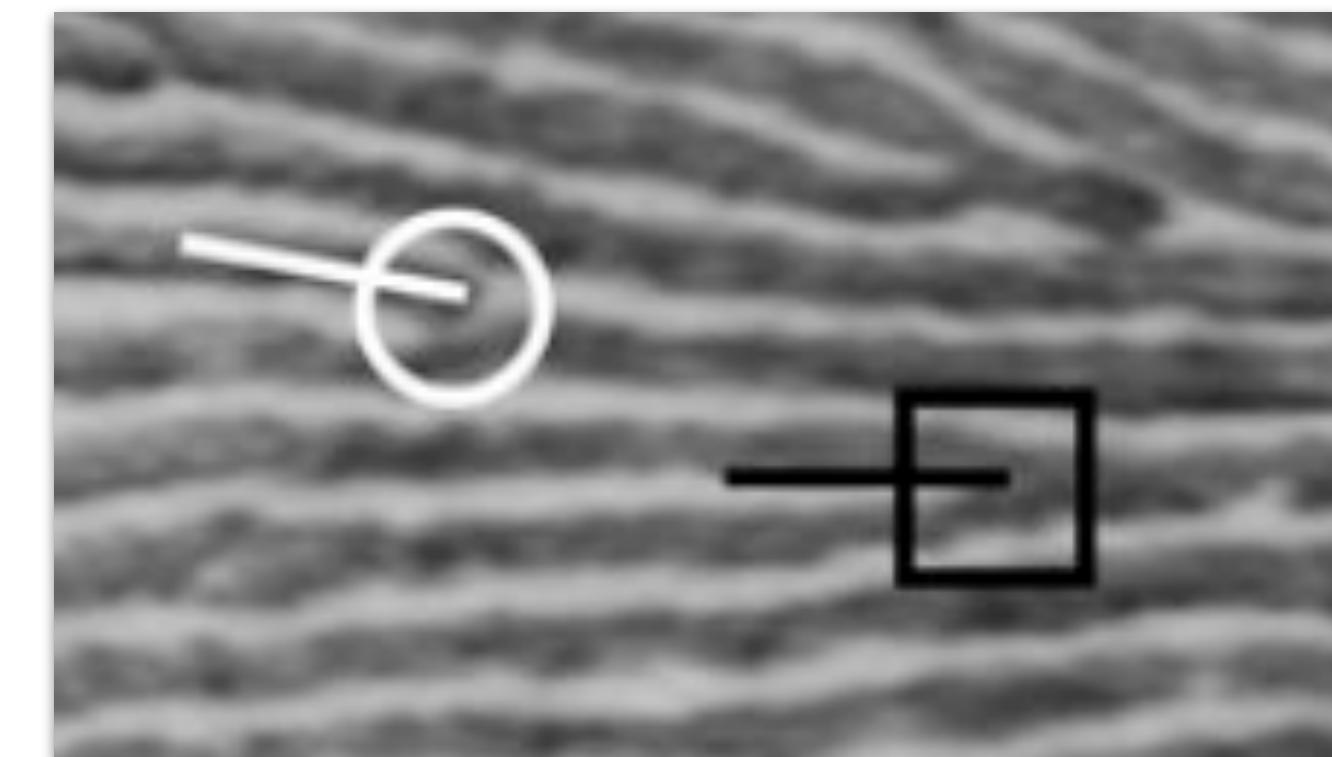


# Features

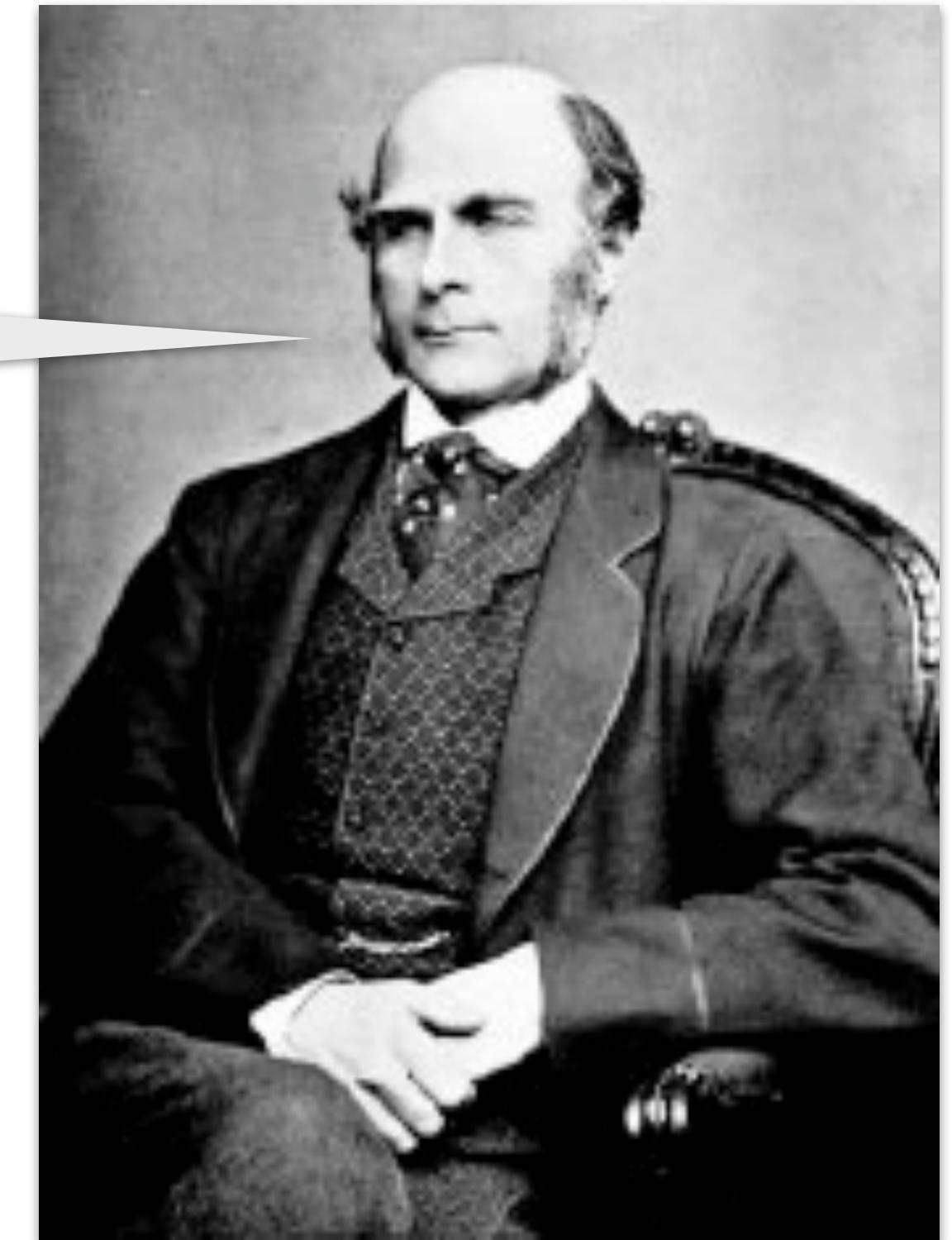
## Level-2 Features

### 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



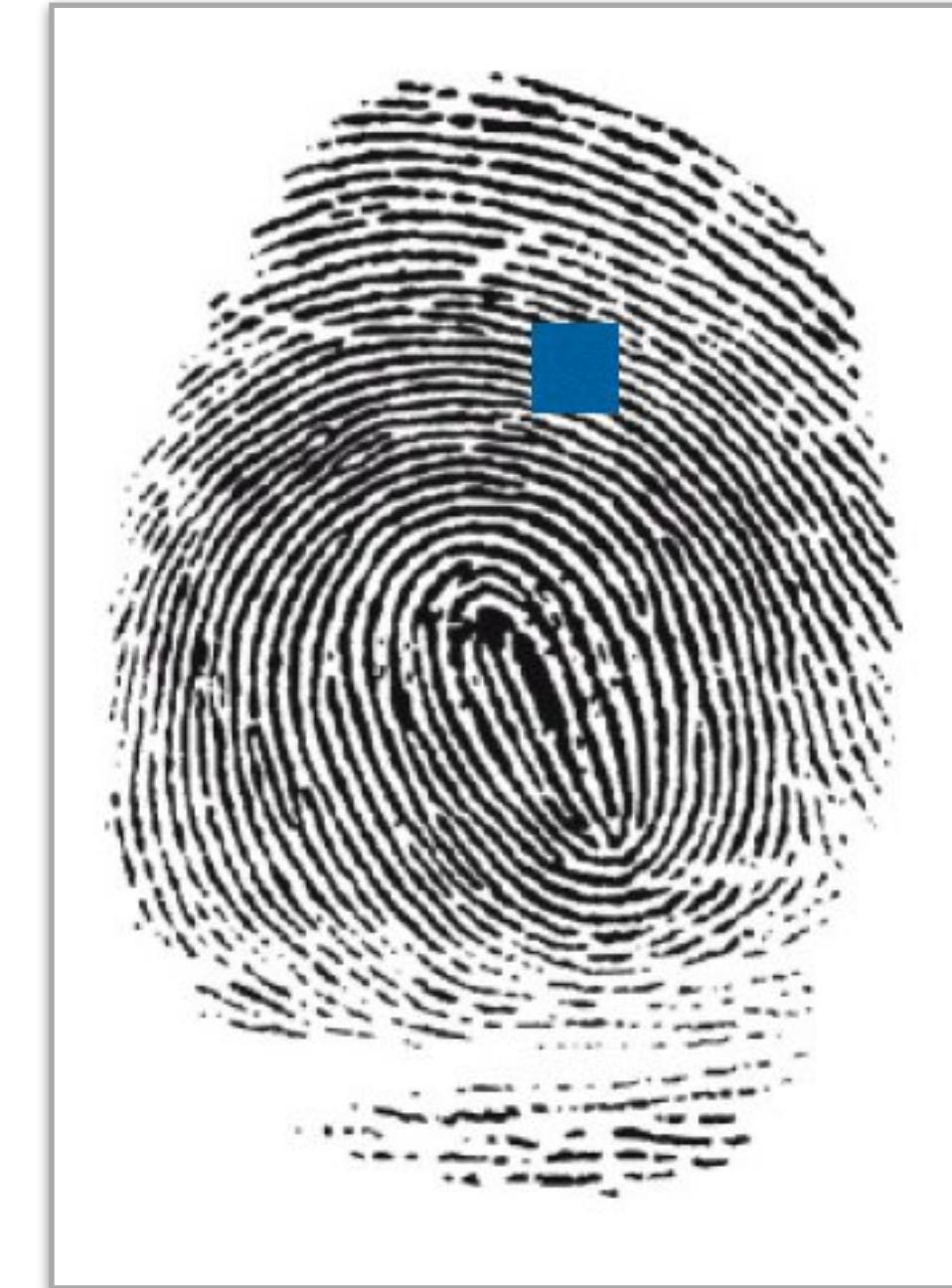
# Features

## 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

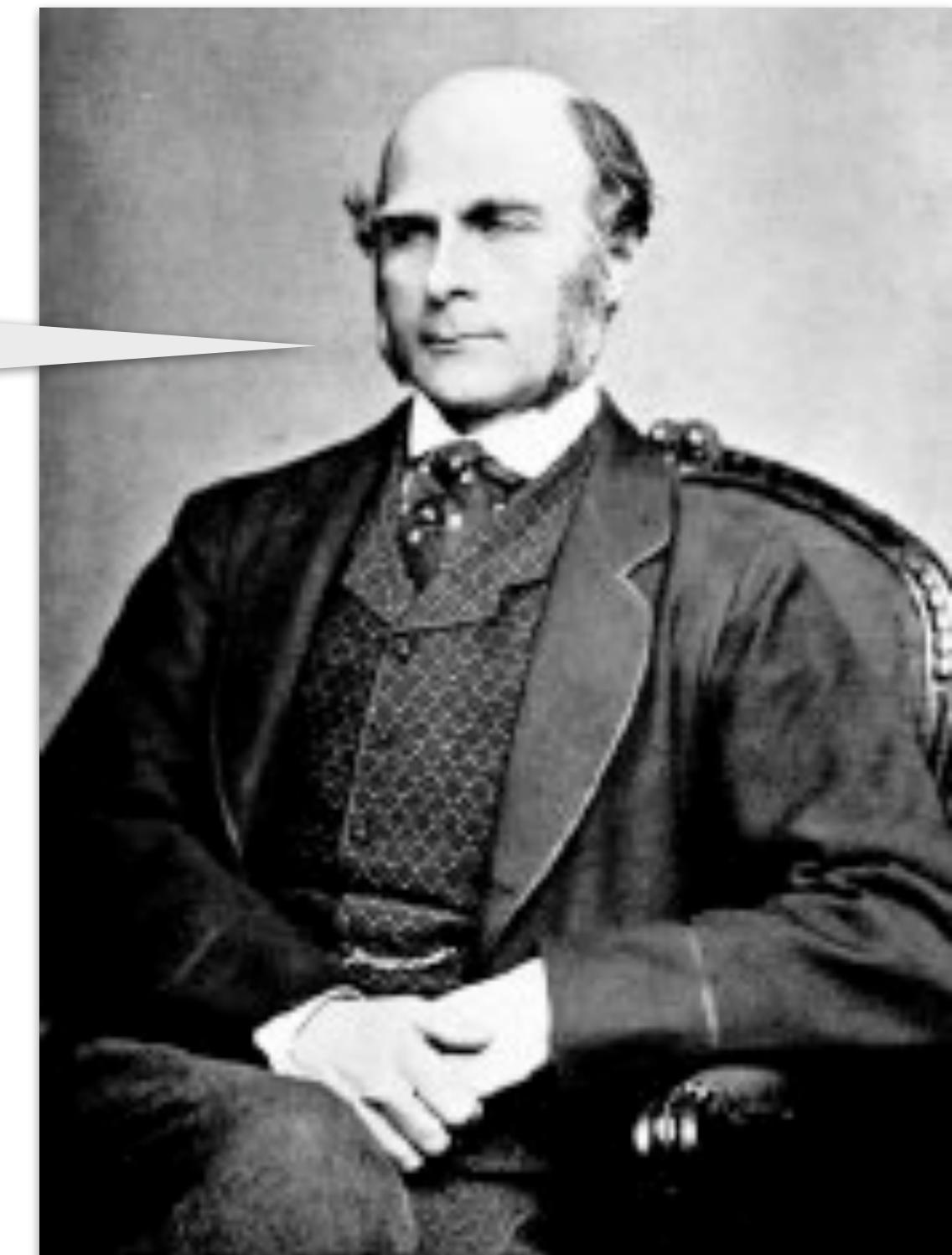
## Level-2 Features

### 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.



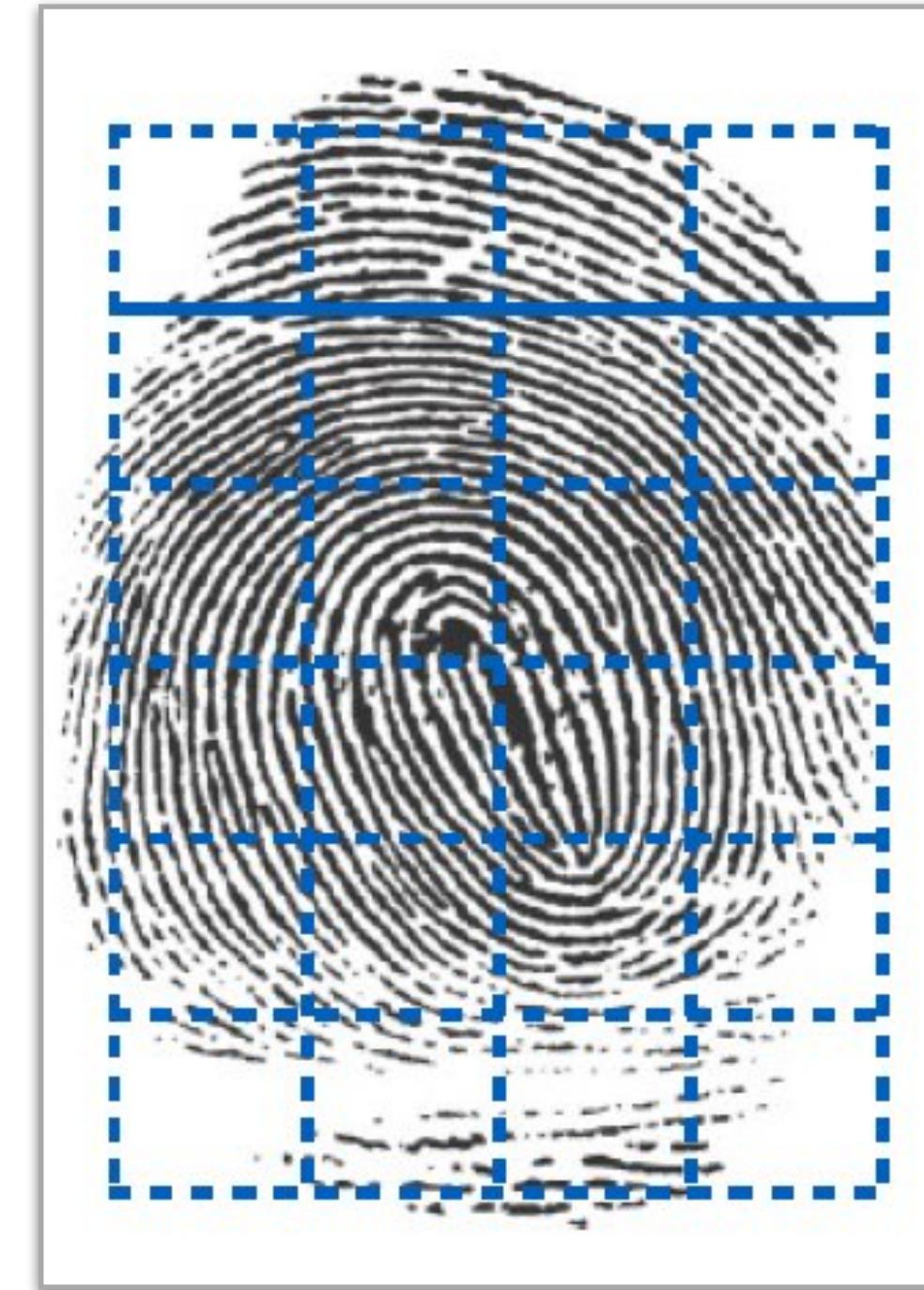
# Features

## Level-2 Features

### Galton's Estimate

A typical fingerprint consists of 24 six-ridge squares.

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



Source:  
Dr. Walter Scheirer

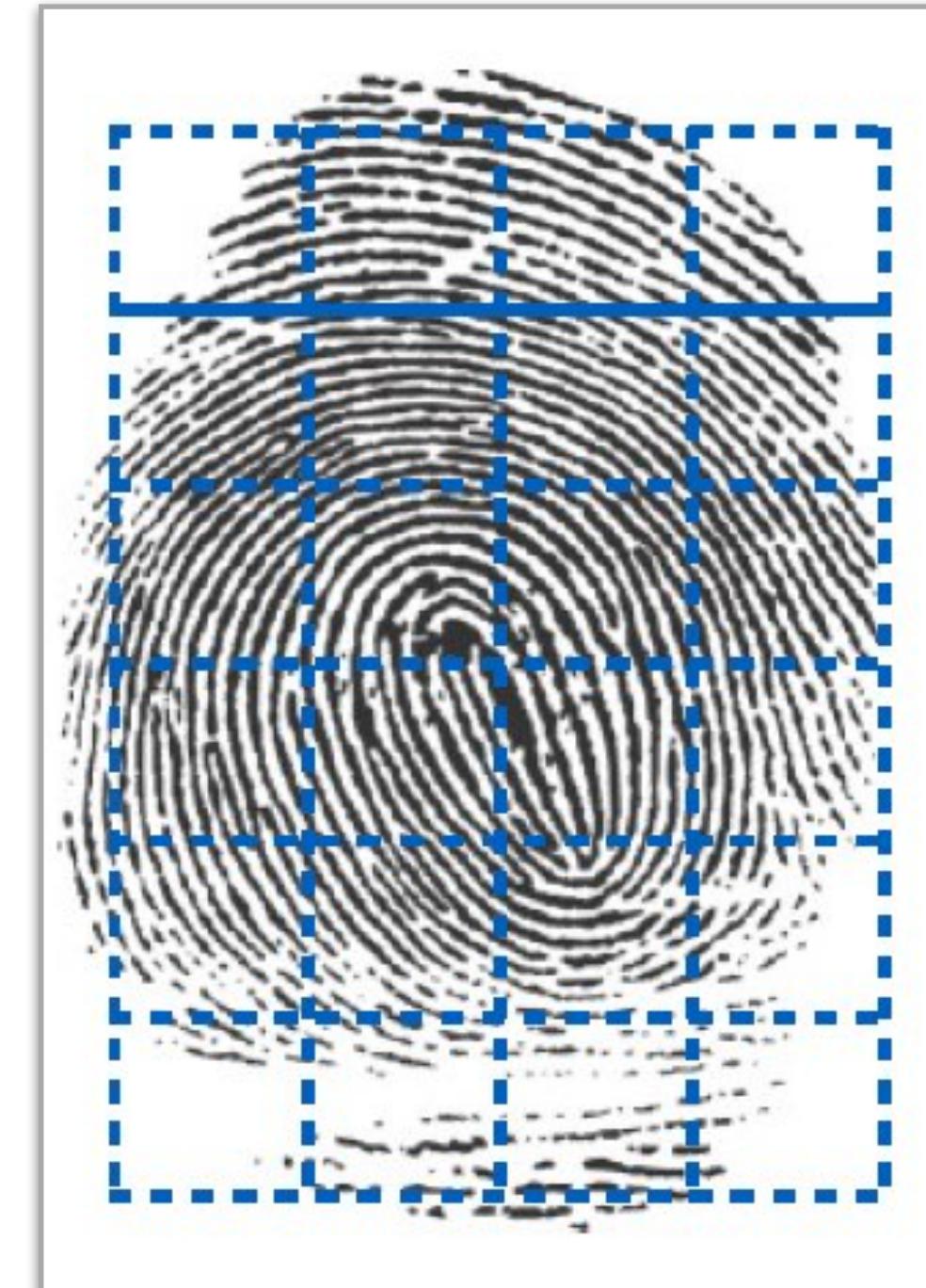
# Features

## 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

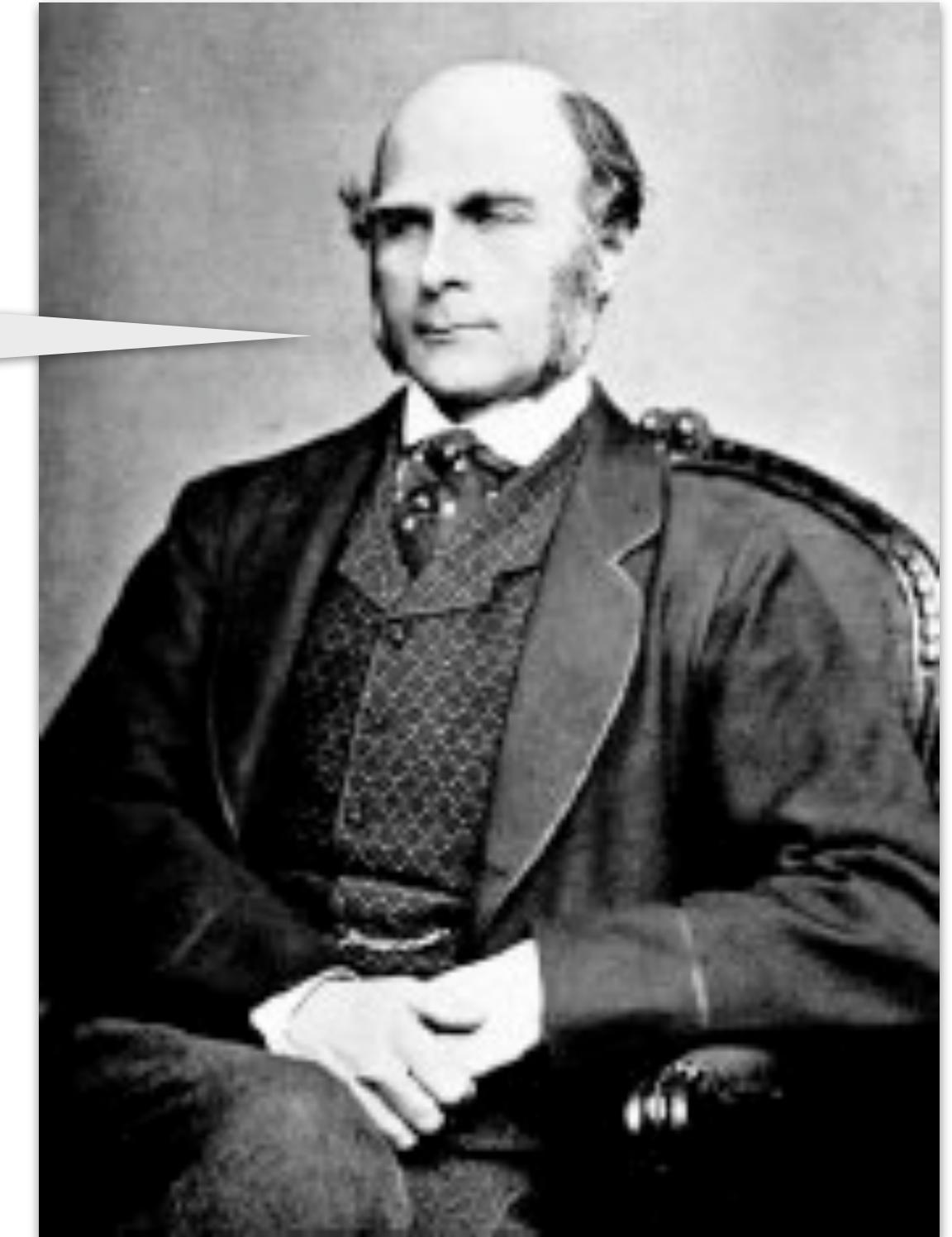
## Level-2 Features

### 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](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**

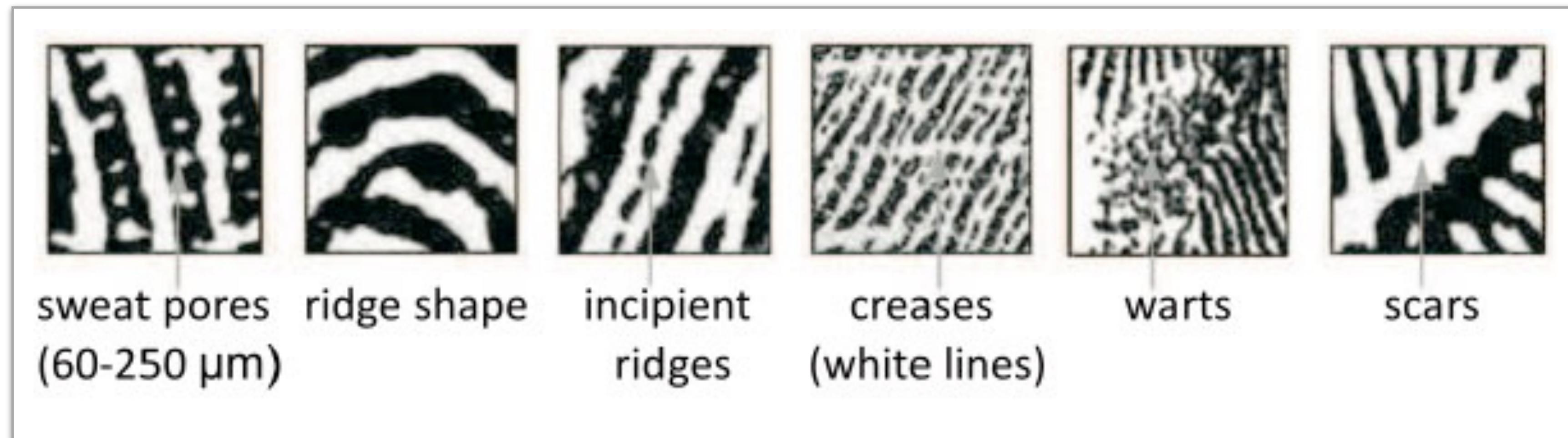


# Features

## 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>

# What's Next?

## More about fingerprints

Fingerprint acquisition methods.

Fingerprint enhancement methods.

Fingerprint data representation.

