Fingerprint Recognition I

COMP 388-002/488-002 Biometrics

Daniel Moreira

Fall 2023

LOYOLA
UNIVERSITY CHICAGO

Today you will…

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

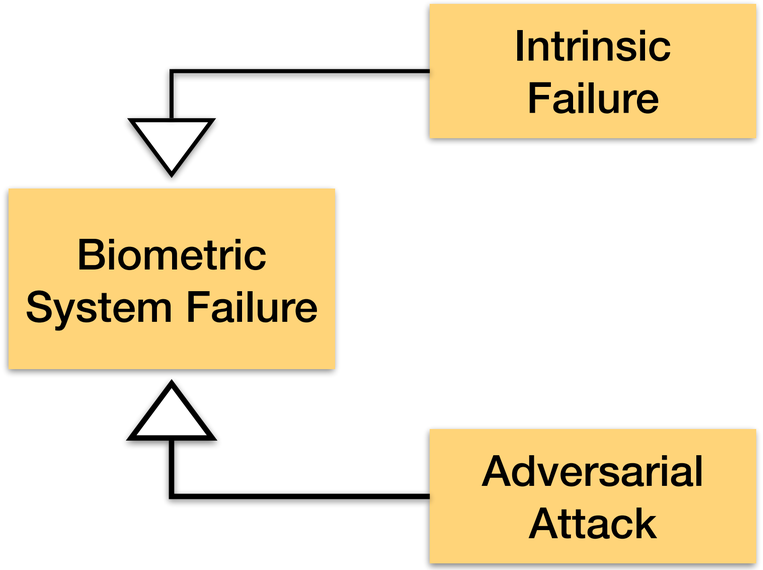
Today’s attendance

Please fill out the form

https://forms.gle/s5jTkByMXAFNd1Nn8

Biometric System Attacks

Threat Model



Biometric System Attacks

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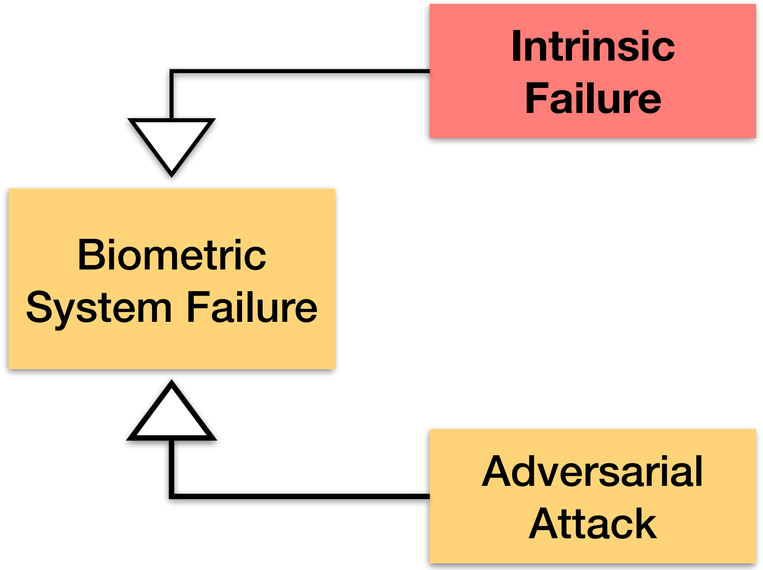

Not attacks
Errors due to the limitation of the solutions and due to hardware stress.

Biometric System Attacks

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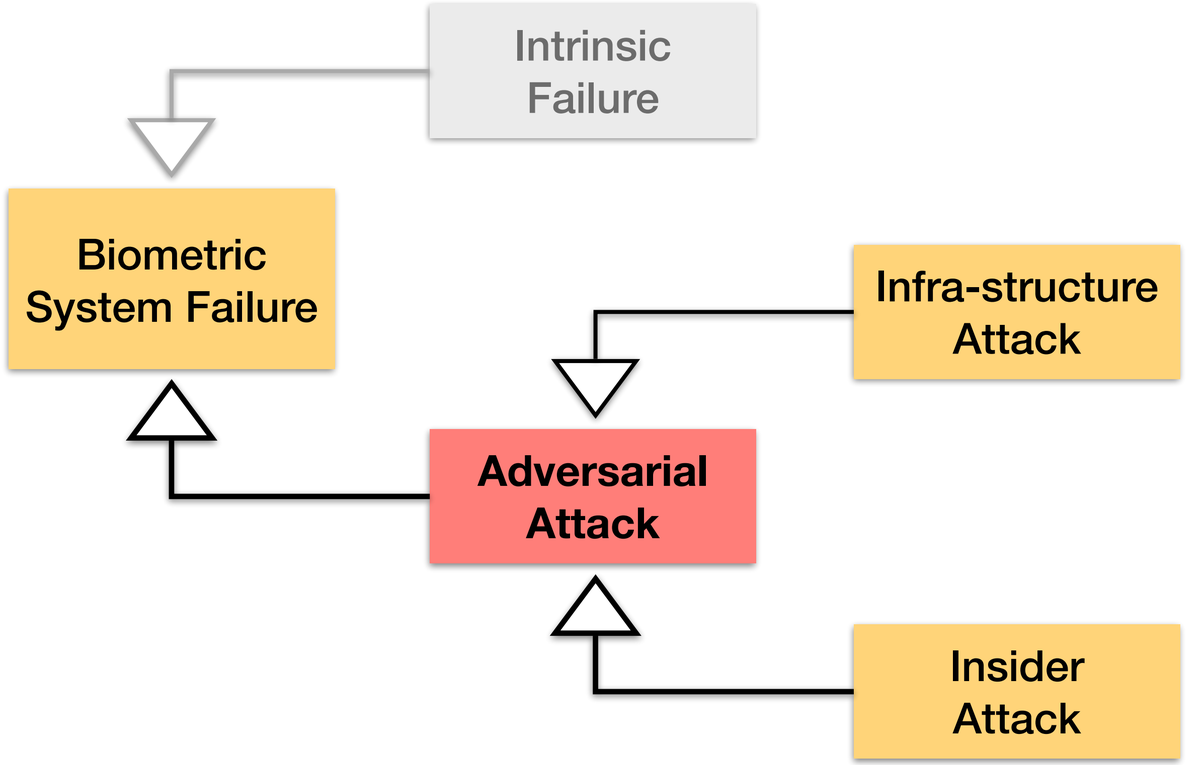

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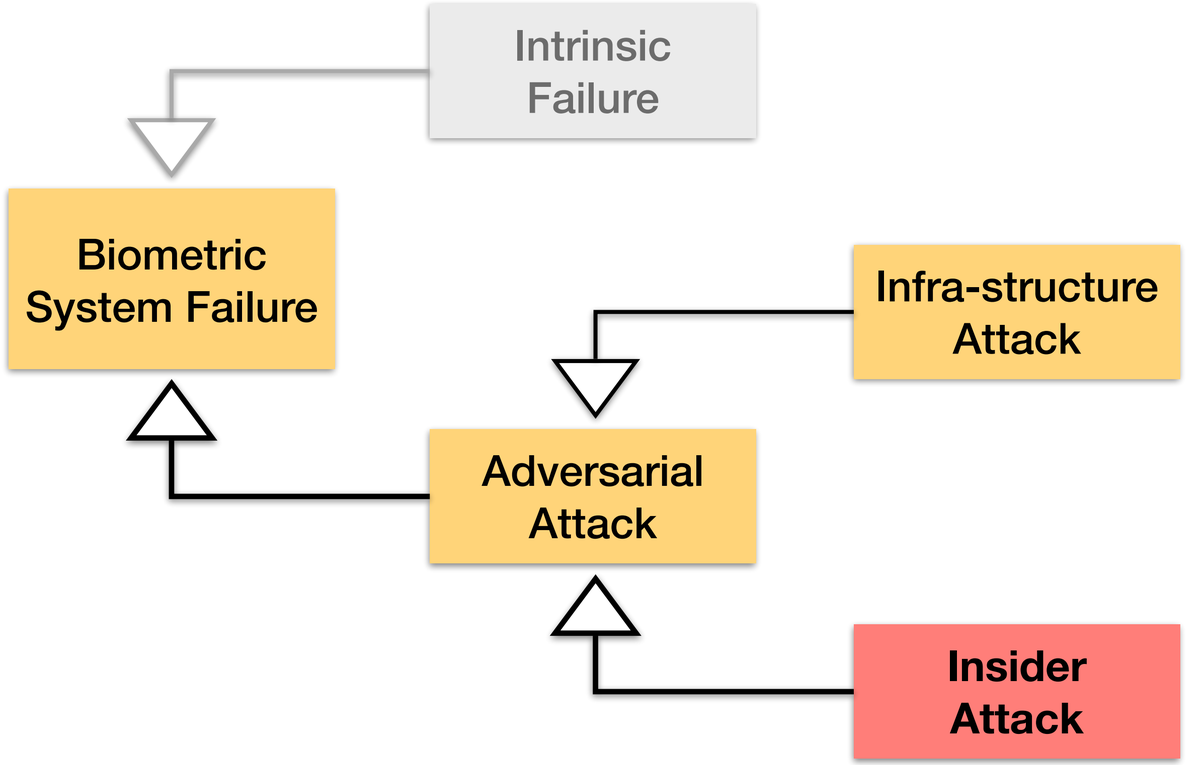
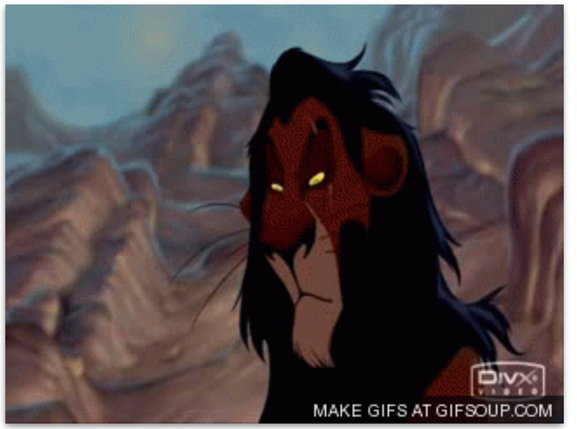
Biometric System Attacks

Threat Model

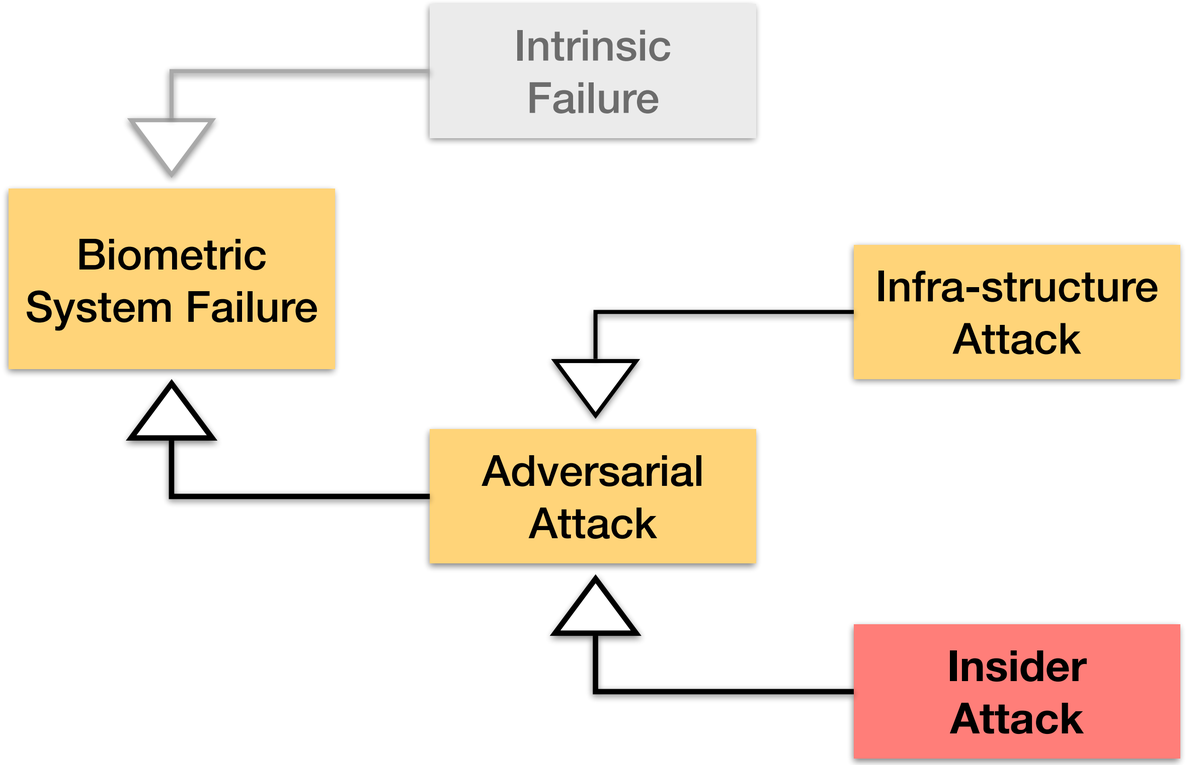


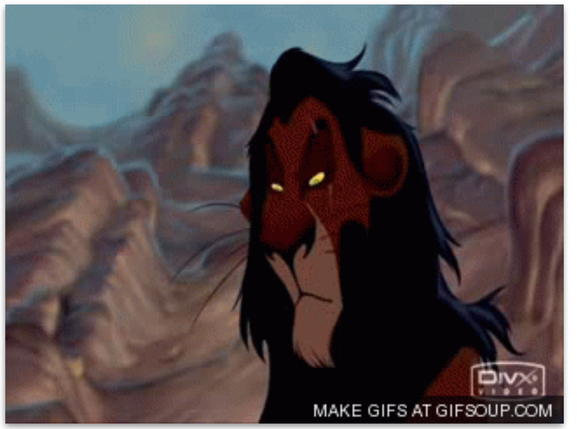


Friendly Fire
Attacks from *insiders* (system users or operators).
What can we do?

Biometric System Attacks

Threat Model



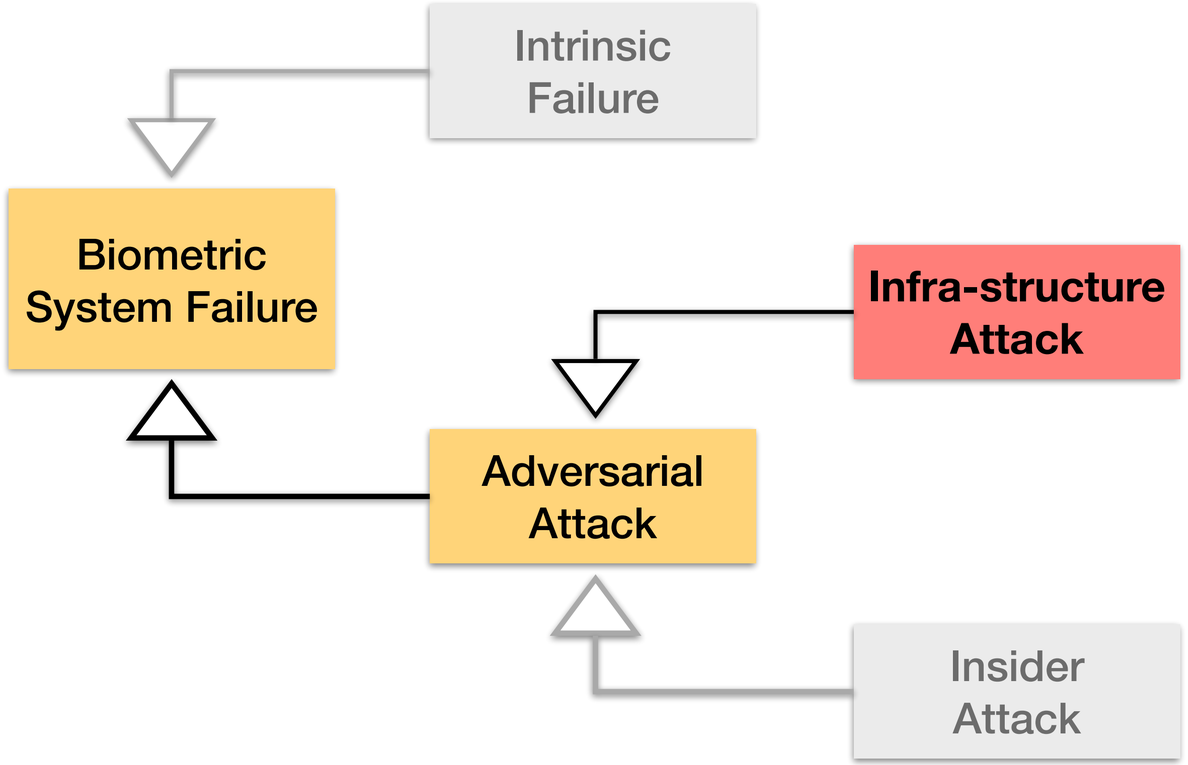


Friendly Fire

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

Biometric System Attacks

Threat Model



Types

Black box

White box

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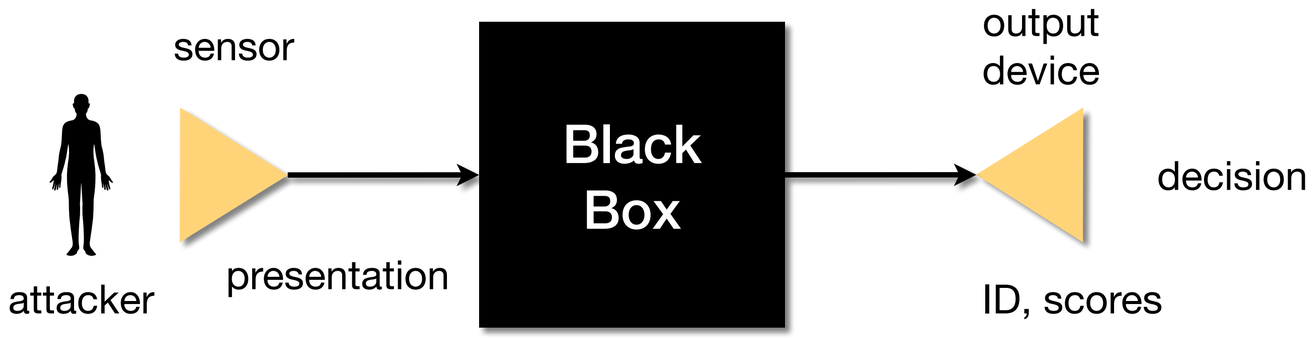
Biometric System Attacks

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?

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NEWS

Taisha Walker, Reporter

Published: September 18, 2019, 6:57 pm

Tags: News, Local, Crime

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Divorce deception: Man forges wife's name on divorce papers, police say

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.

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).

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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.dailydot.com/debug/wearable-face-projector-hong-kong-protesters/

https://www.youtube.com/watch?v=_PoudPCevN0

Biometric System Attacks

Spoofing

When the attacker presents to the system a forged non-live trait.

Possible solution: detect trait liveness.

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.

Biometric System Attacks

Spoofing

When the attacker presents to the system a forged non-live trait.

What can we do?

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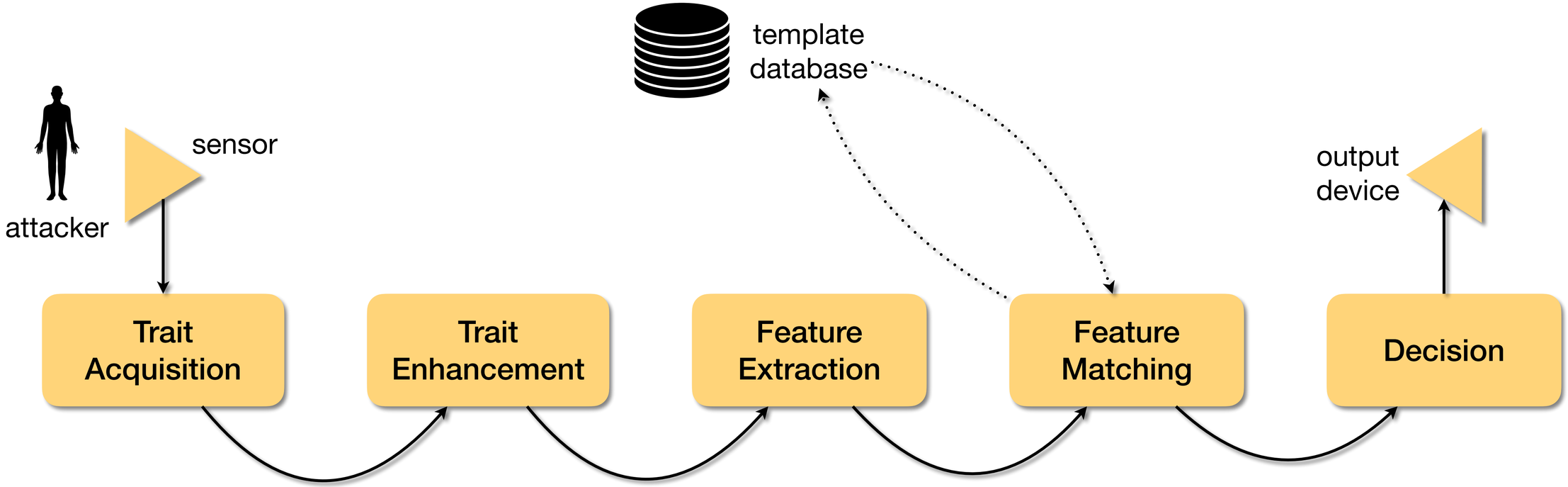
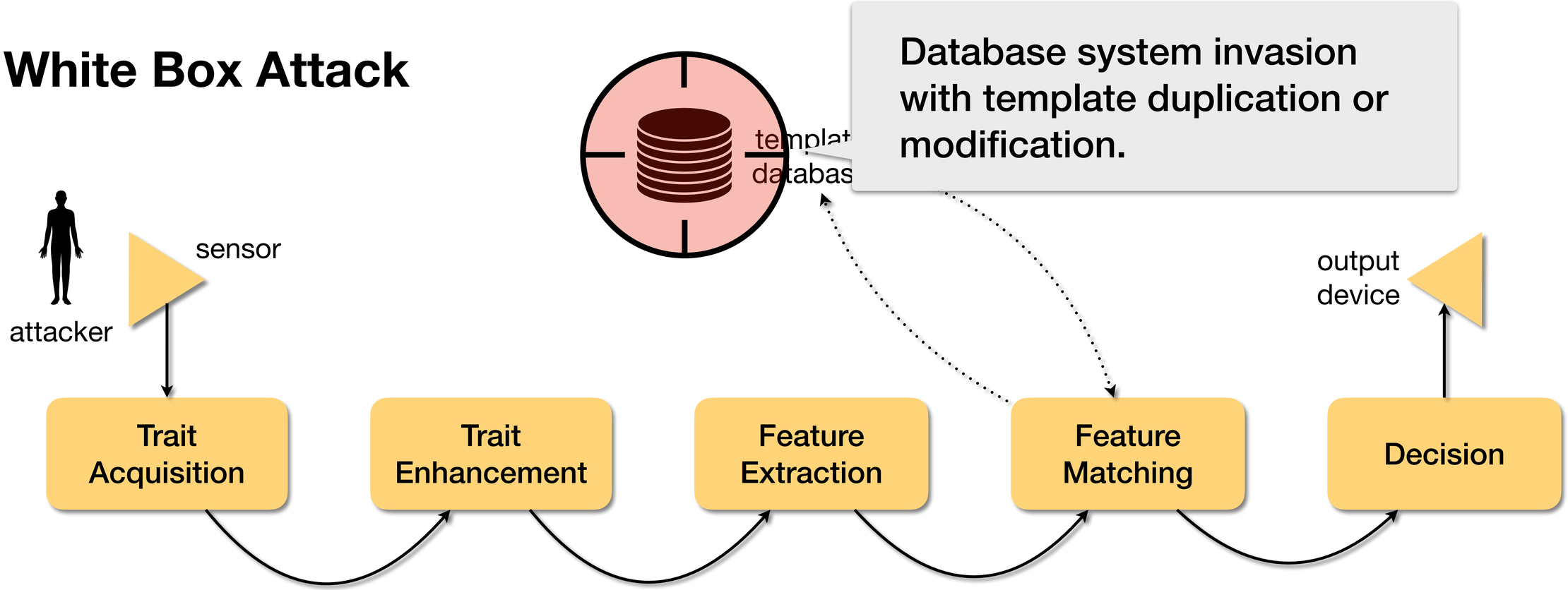
Biometric System Attacks

White Box Attack



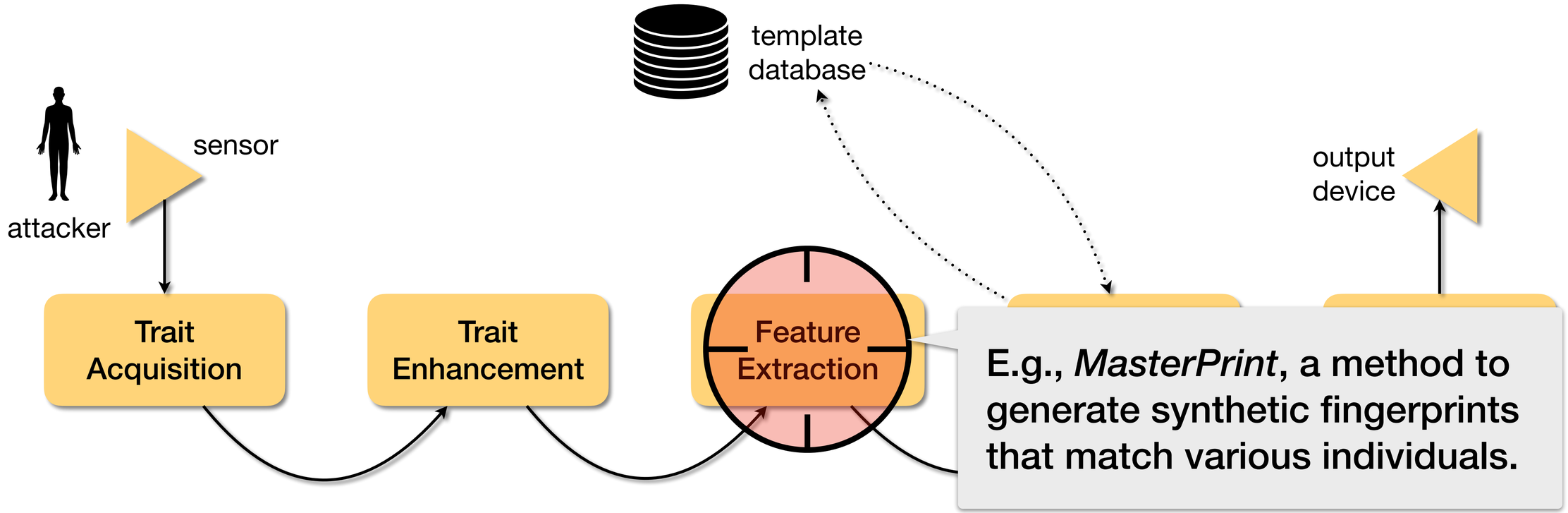
Biometric System Attacks

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

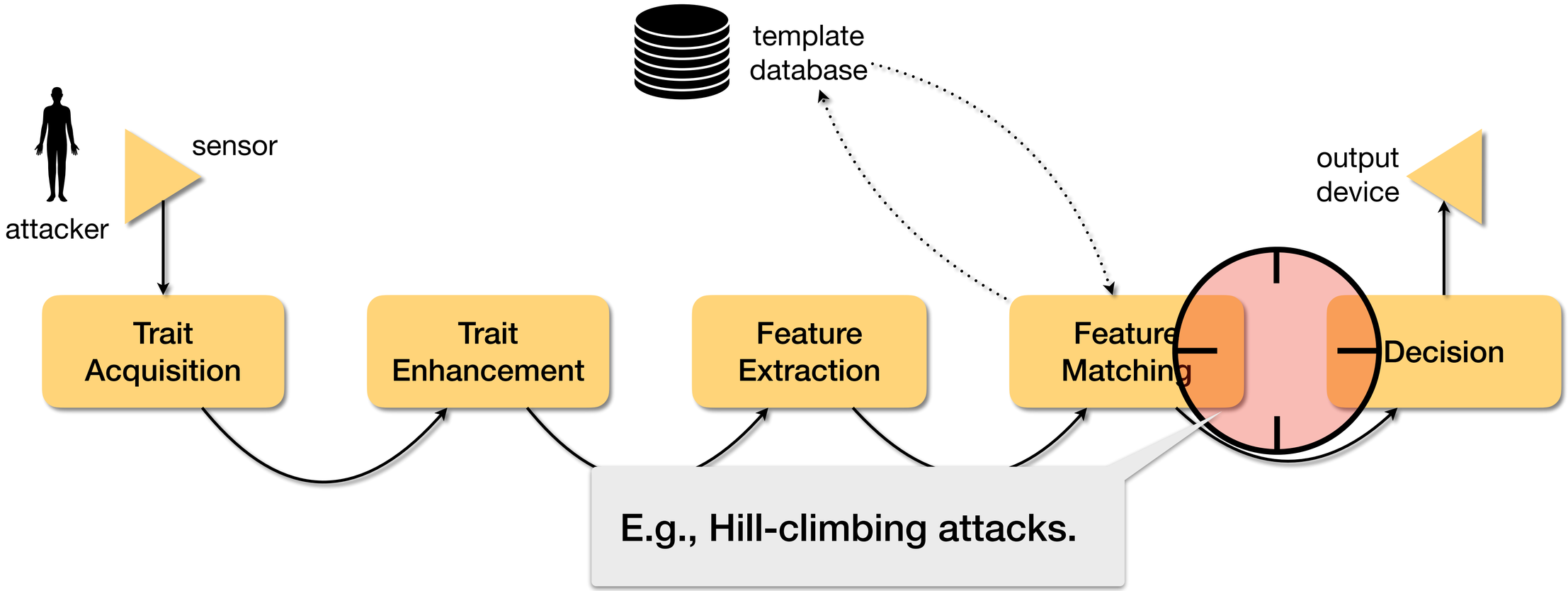
Aditi Roy, *Student Member, IEEE*, Nasir Memon, *Fellow, IEEE*, and Arun Ross, *Senior Member, IEEE*

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

https://www.cse.msu.edu/~rossarun/pubs/RoyMemonRossMasterPrint_TIFS2017.pdf

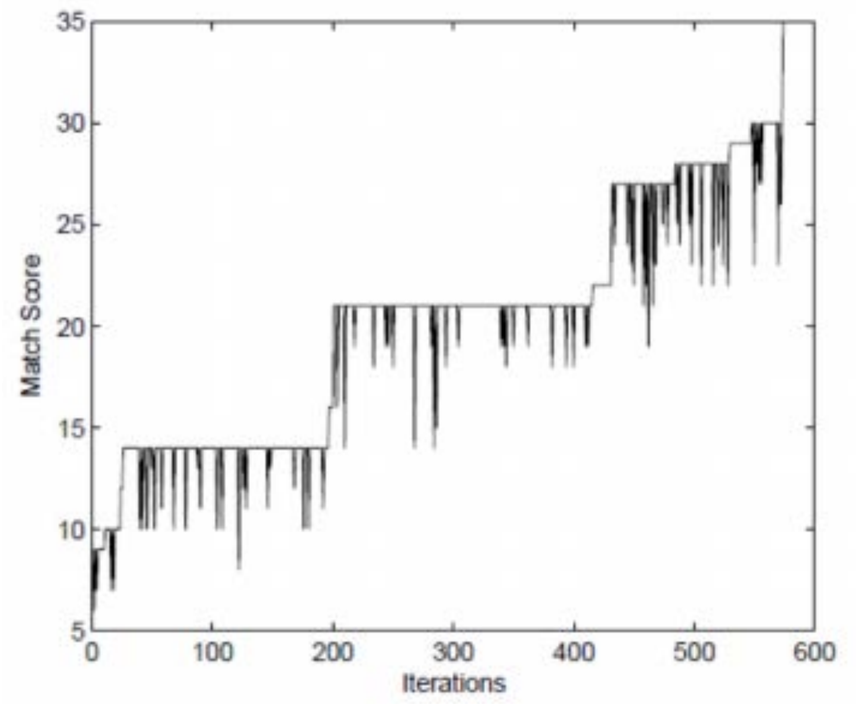
Biometric System Attacks

White Box Attack



Biometric System Attacks

Hill-climbing Attack
E.g. Fingerprints

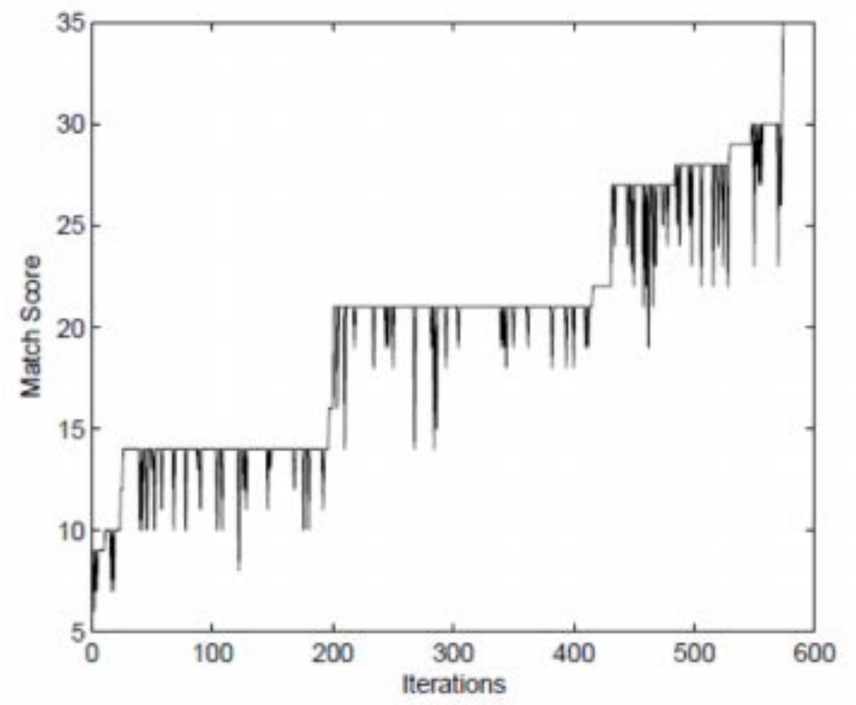


The attacker iteratively provides synthetic trait samples to the system. At each iteration, the attacker observes how the similarity scores are progressing.

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.

Martinez-Diaz et al.
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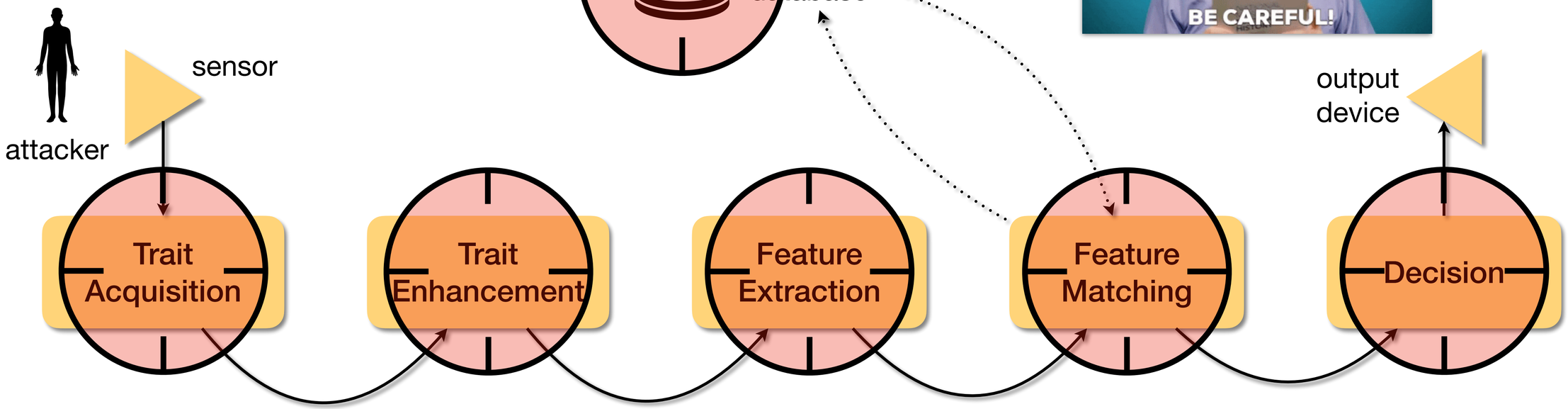
Biometric System Attacks

White Box Attack



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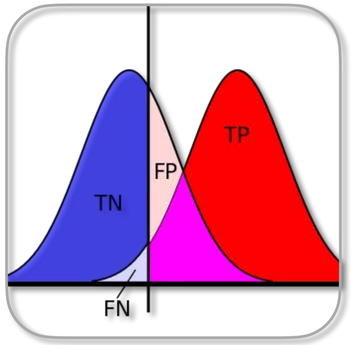
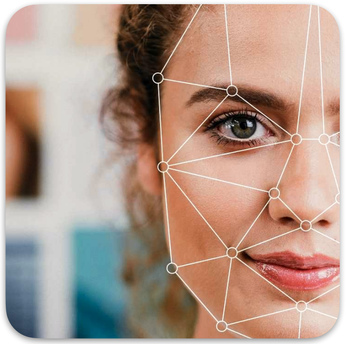
Course Overview

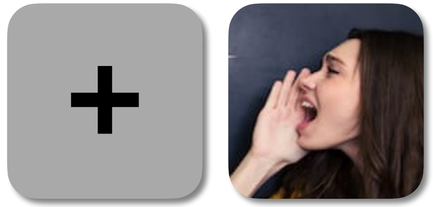
Content



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

Course Overview

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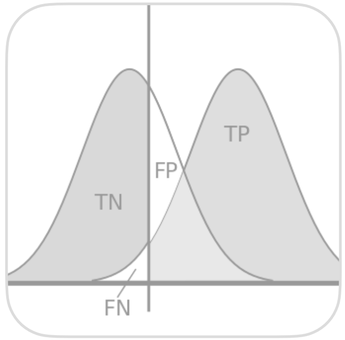

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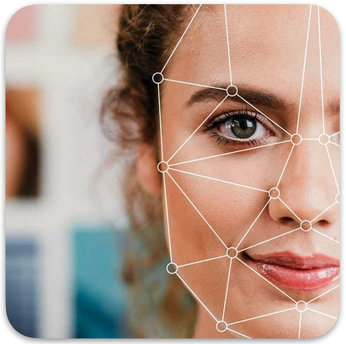

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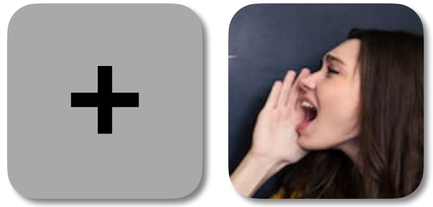

Alternative Traits and Fusion
Concepts

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 Nadakumar
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

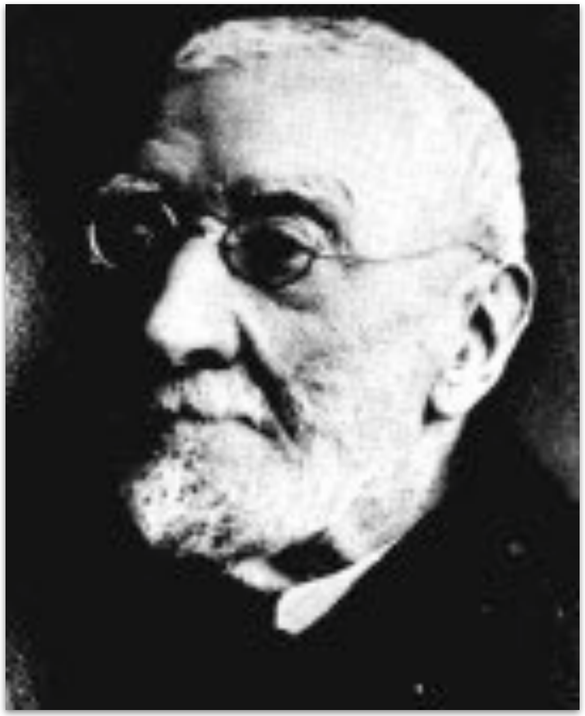
Sir William Herschel (UK, 1858)
Pioneering usage of fingerprints for identification.

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.

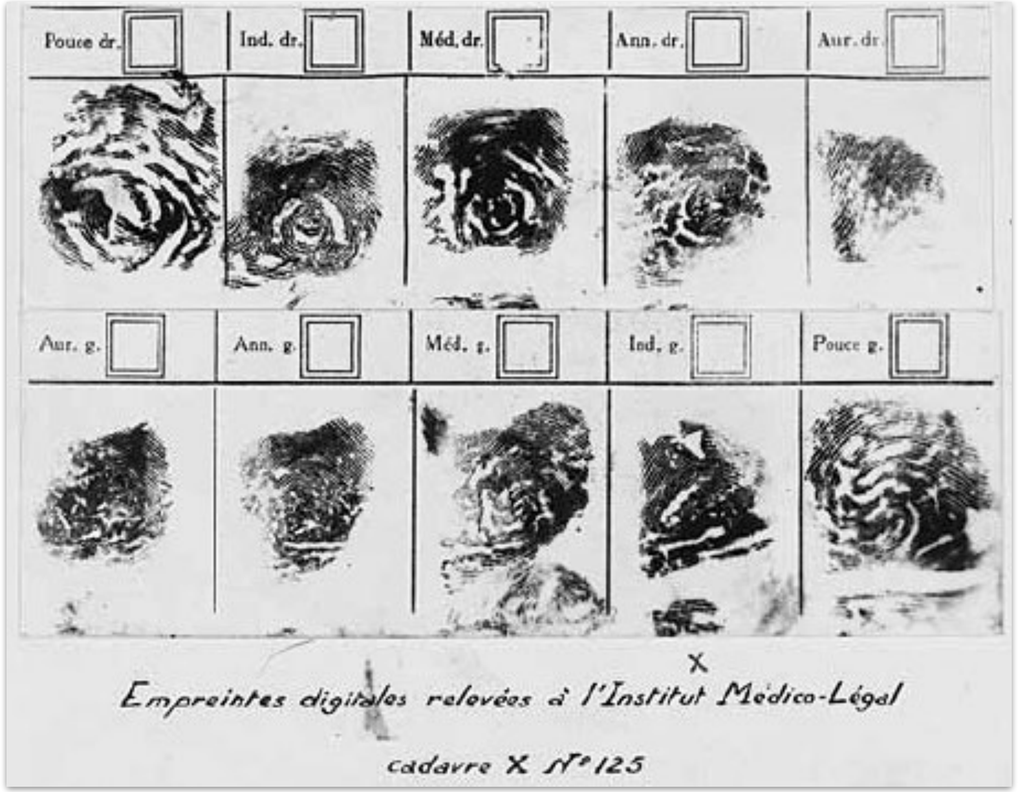
Collected a latent fingerprint from a bottle
and identified the author of a theft
in a hospital in Tokyo.



History

Henry Faulds (UK, 1880)
Pioneering usage of fingerprints in a forensic scenario.

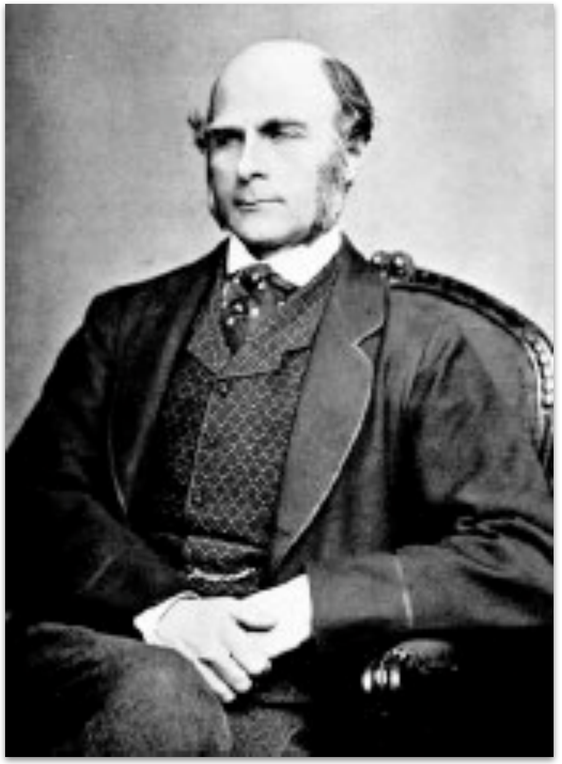
Performed the first experiments showing the uniqueness of fingerprints.



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).



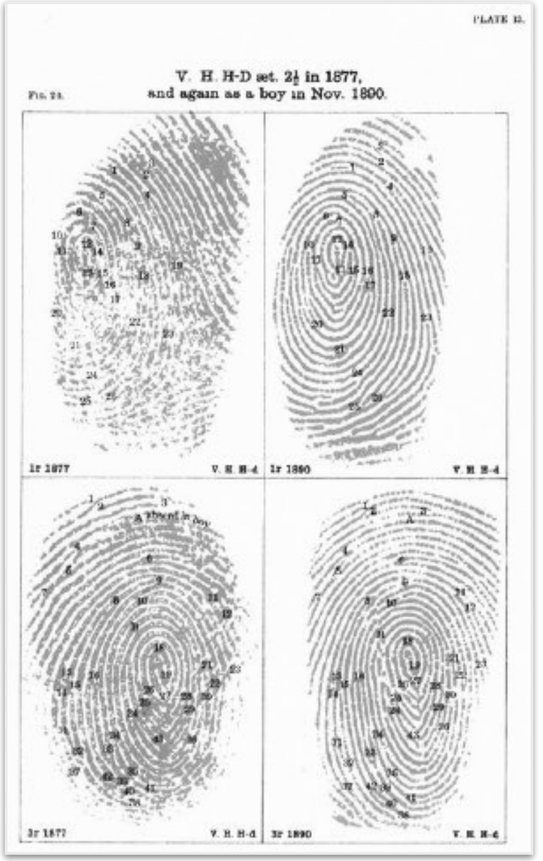
History

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



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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 have 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

History

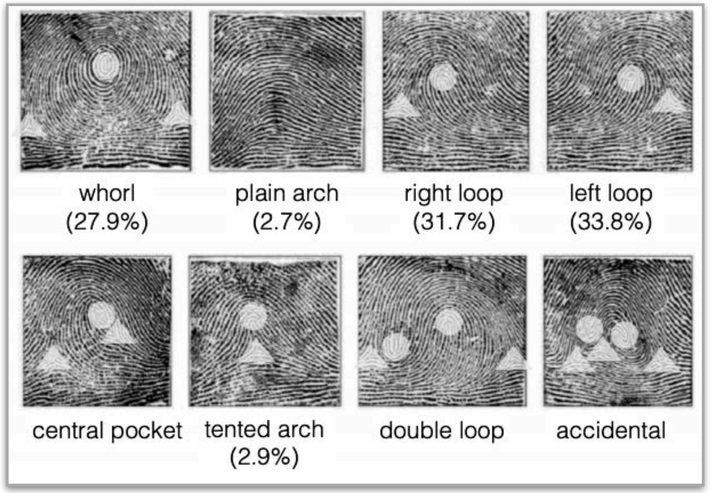
Juan Vucetich (Argentina, 1892)
Pioneering criminal conviction based on fingerprints.

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

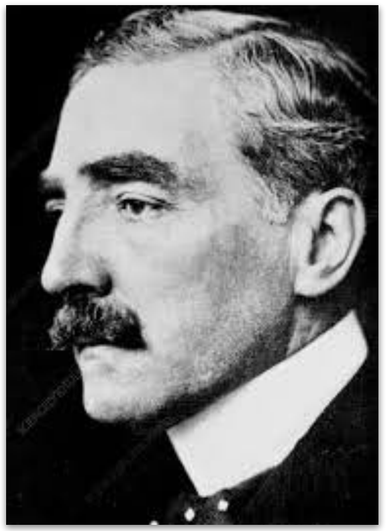
History

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.

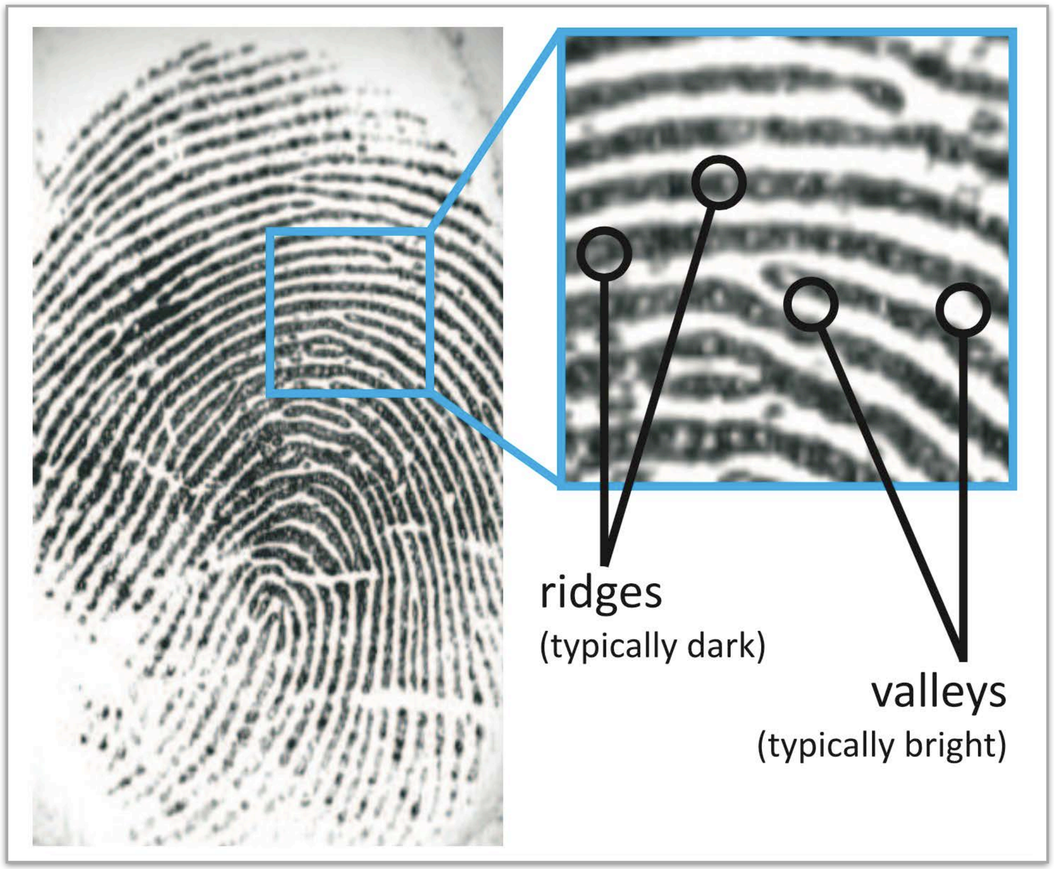
International Association for Identification, 1915
Creation of the largest forensic association in the world.

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?

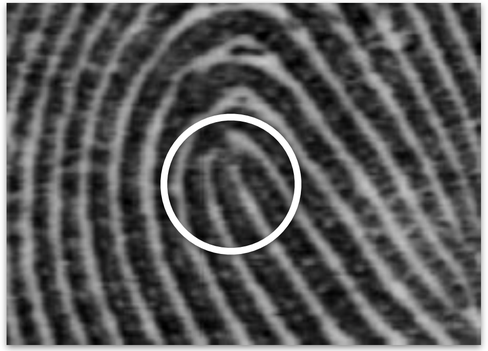
Beyond Ridges and Valleys
Three types of features, from coarse to fine levels:

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

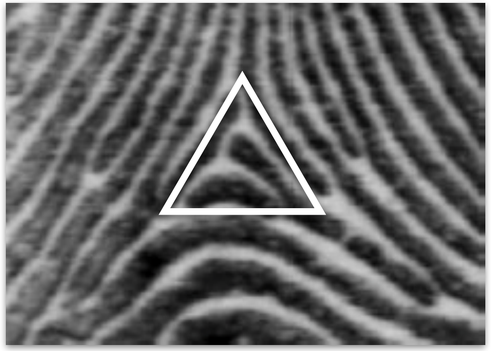
Features

Level-1 Features
Observe singular points and core.
Useful capture resolution: 250 ppi (pixels per inch)

Singular Points



loop



delta

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

Core

Up-most singular point

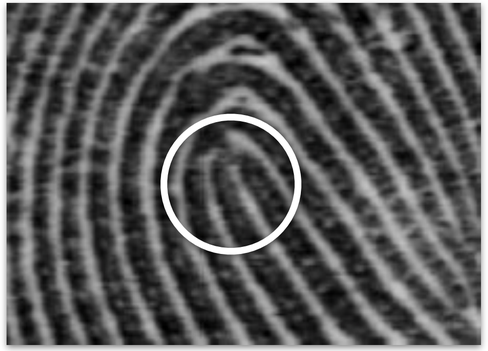
or (in case of no singular point)

Point of maximum ridge curvature.

Features

Level-1 Features
Observe singular points and core.

Usage of Singular Points and Core



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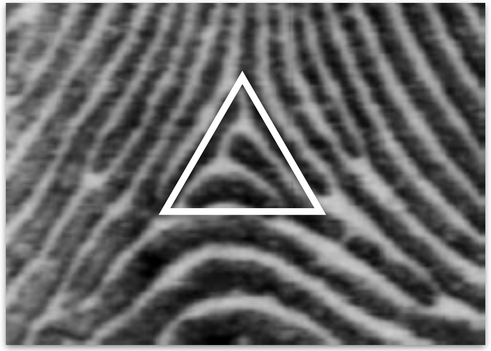


delta

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

Alignment of two samples.
Fingerprint classification.

Features

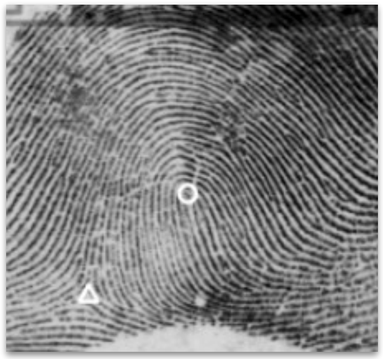
Fingerprint Classification

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

plain arch
4%

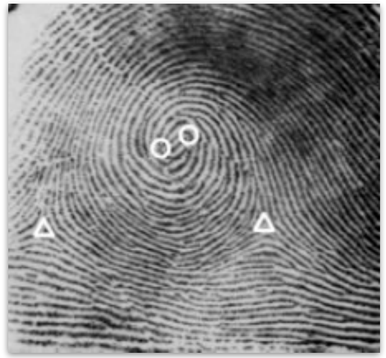
tented arch
3%

left loop

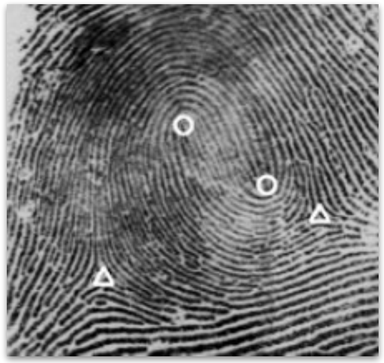


right loop

65%



whorl
24%



twin loop
4%

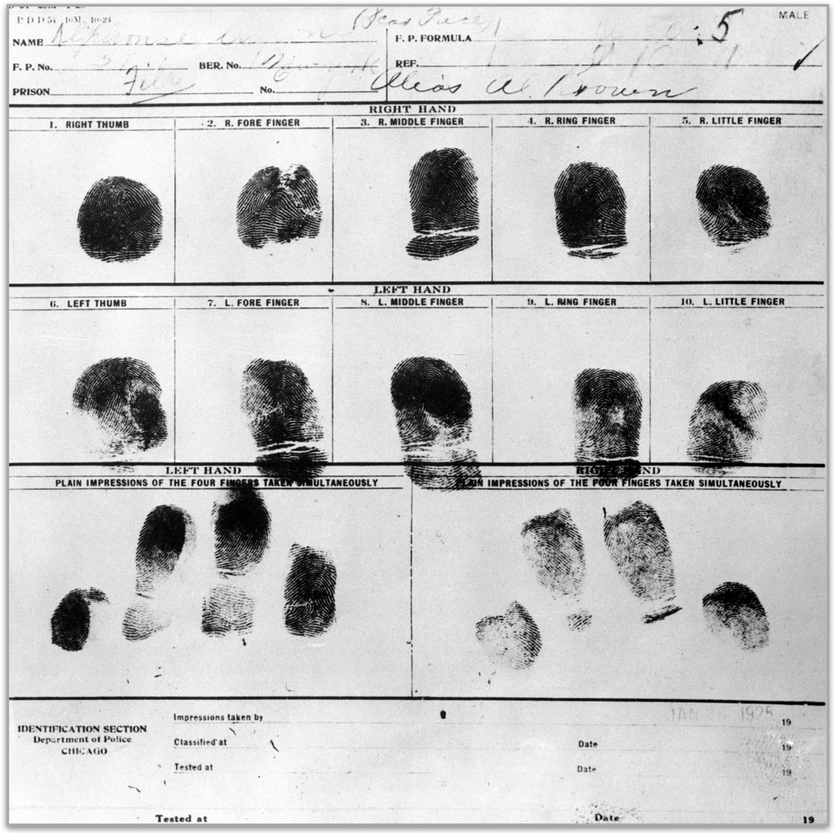
Percentages: frequencies of observation.

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.

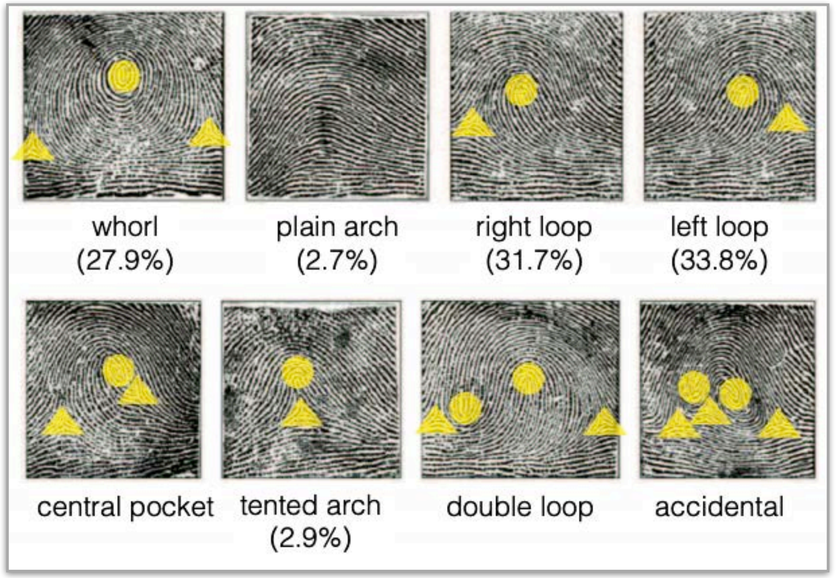


Features

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**.



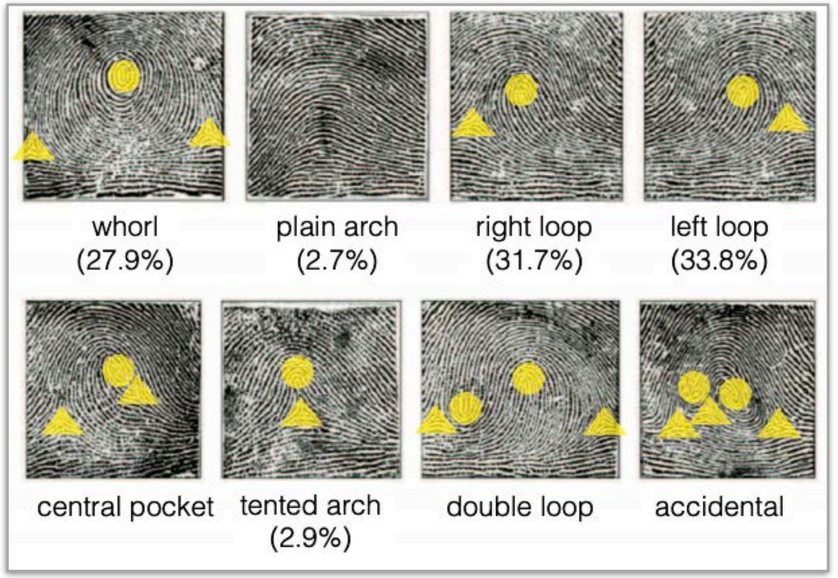
Henry's features, an alternative classification of level-1 features with 8 classes.

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?

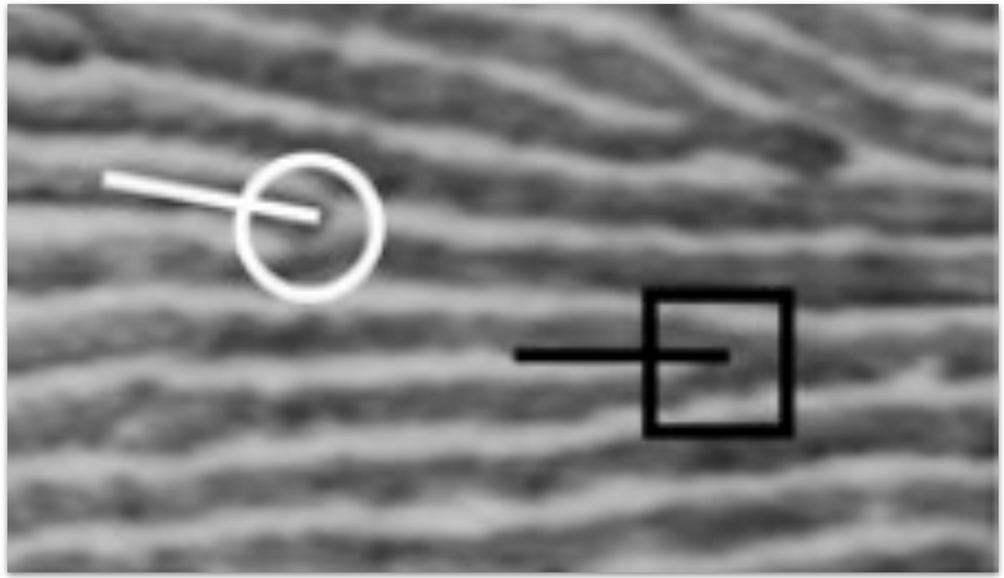
Beyond Ridges and Valleys
Three types of features, from coarse to fine levels:

- 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

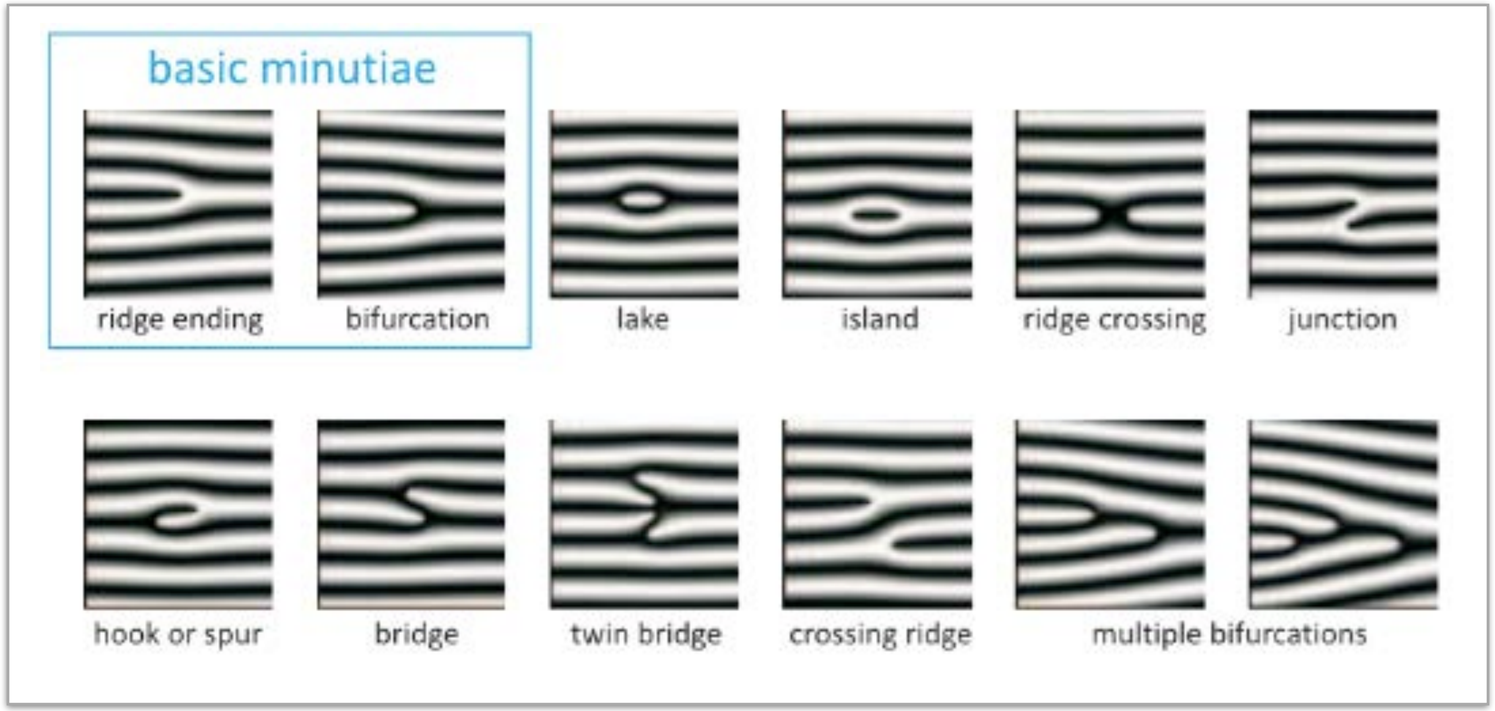


Ridge Bifurcation

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

Features

Level-2 Features
Alternative minutiae.



Source:
www.optel.com.pl

Features

Level-2 Features

Usage of minutiae
Fingerprint matching.

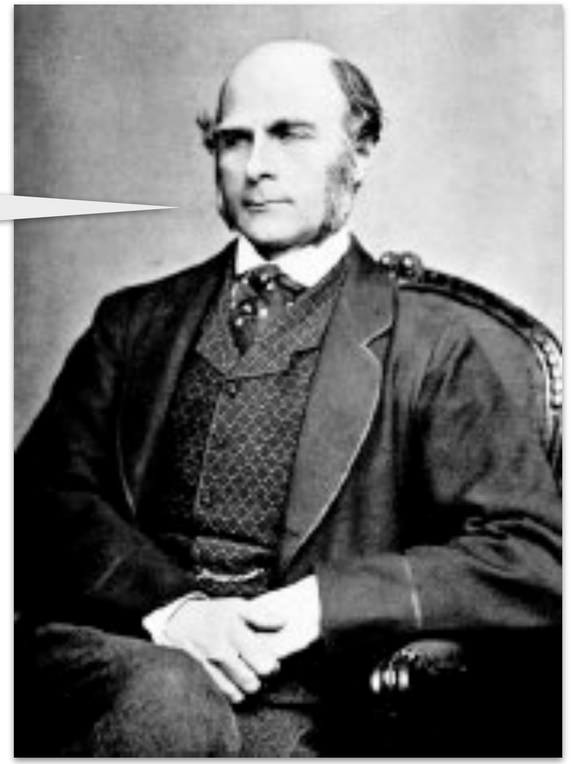
More details on **how** to do it
in the upcoming classes.

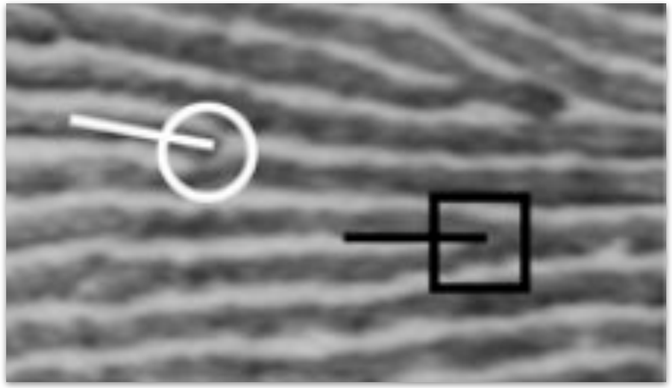
Features

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.





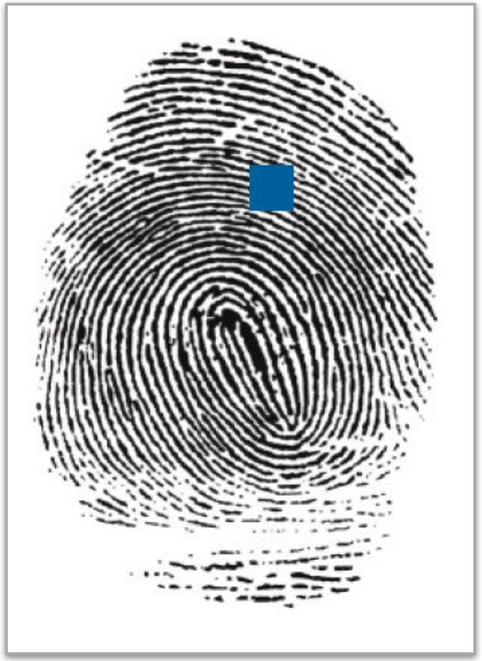
Jain, Ross, and Nadakumar
Introduction to Biometrics
Springer Books, 2011

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?



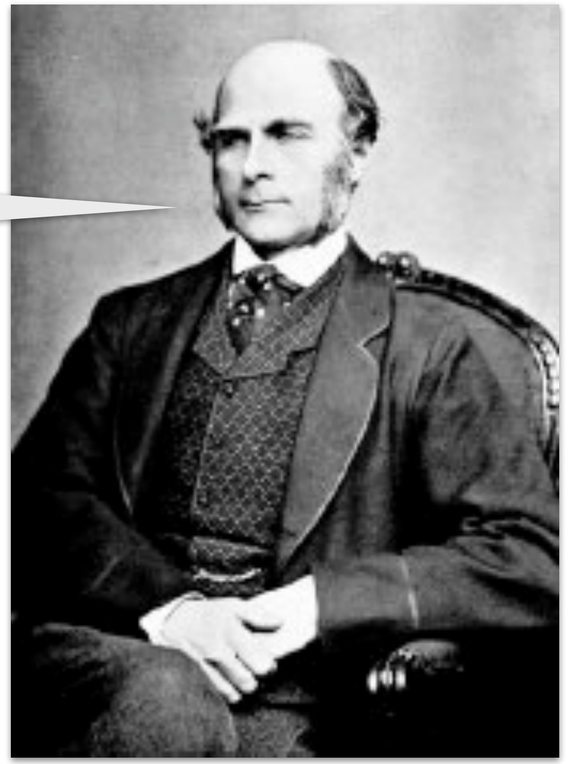
Source:
Dr. Walter Scheirer

Features

Level-2 Features

Galton's Estimate

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



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?

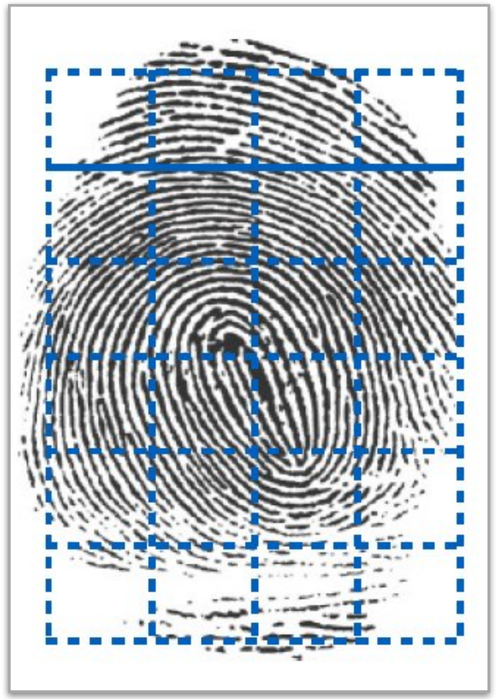
Features

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

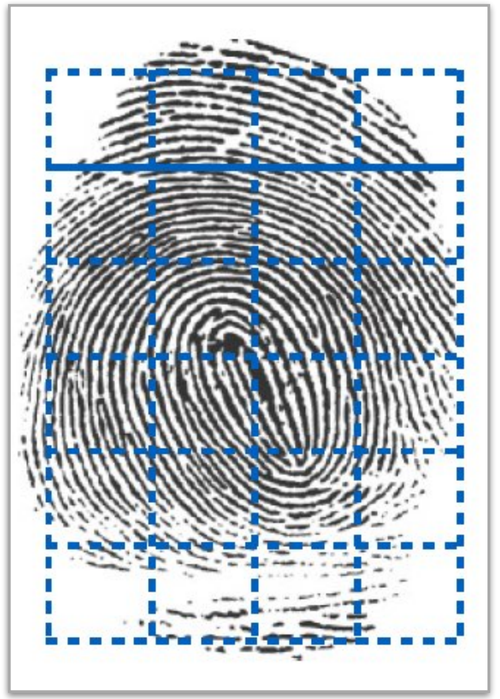
Features

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

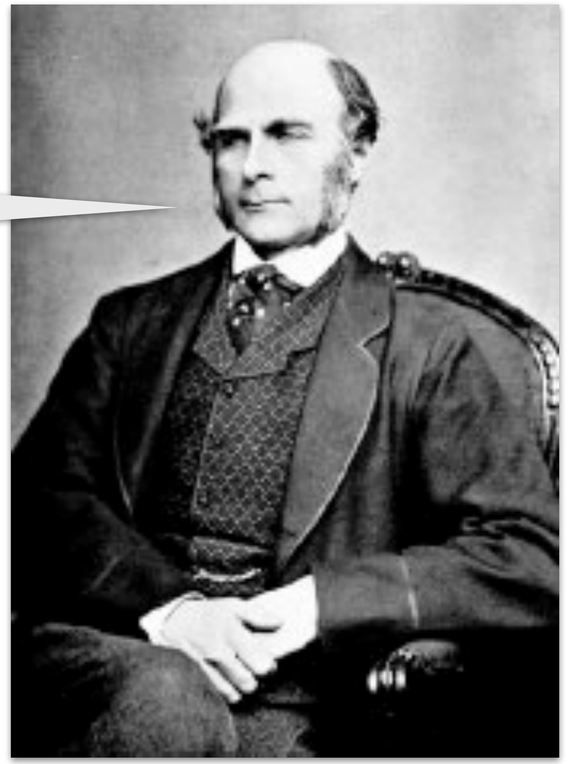
Level-2 Features

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

Features

What do we observe in fingerprints?

Beyond Ridges and Valleys
Three types of features, from coarse to fine levels:

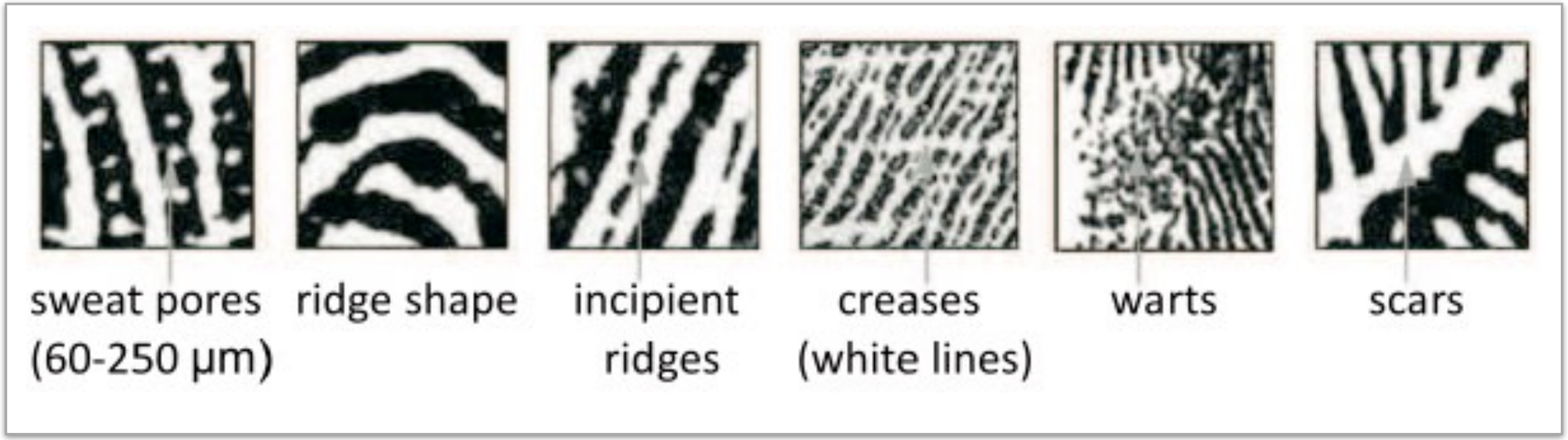
- Level-1 Features
- Level-2 Features
- **Level-3 Features**

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.