Basics II

COMP 388-002/488-002 Biometrics

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Fall 2025

LOYOLA
UNIVERSITY CHICAGO

Today we will…

Discuss

Biometric systems and their errors.

Metrics to compare Biometric systems.

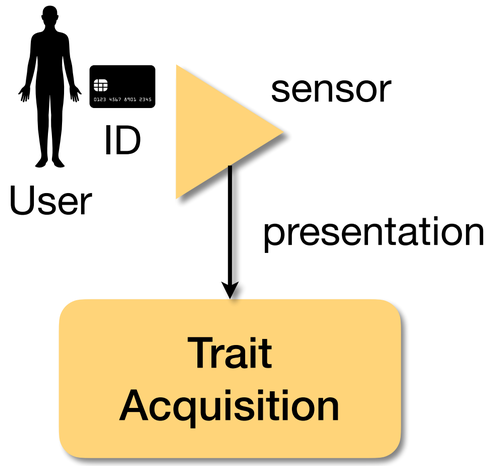
Today's Attendance

Please fill out the form

forms.gle/3ejMkRF21jurS3Ws6

Biometric Systems

Enrollment

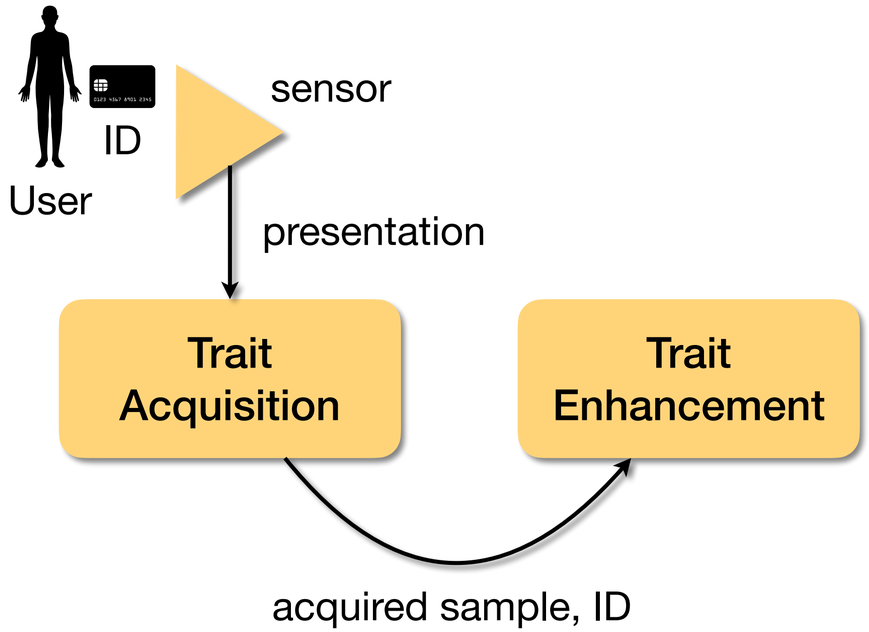


Trait Acquisition
We'll have data-collection classes.
We'll use real-world sensors.

What to observe?
Sensors have different **quality**
(in terms of precision, resolution,
presence of noise, and usability)

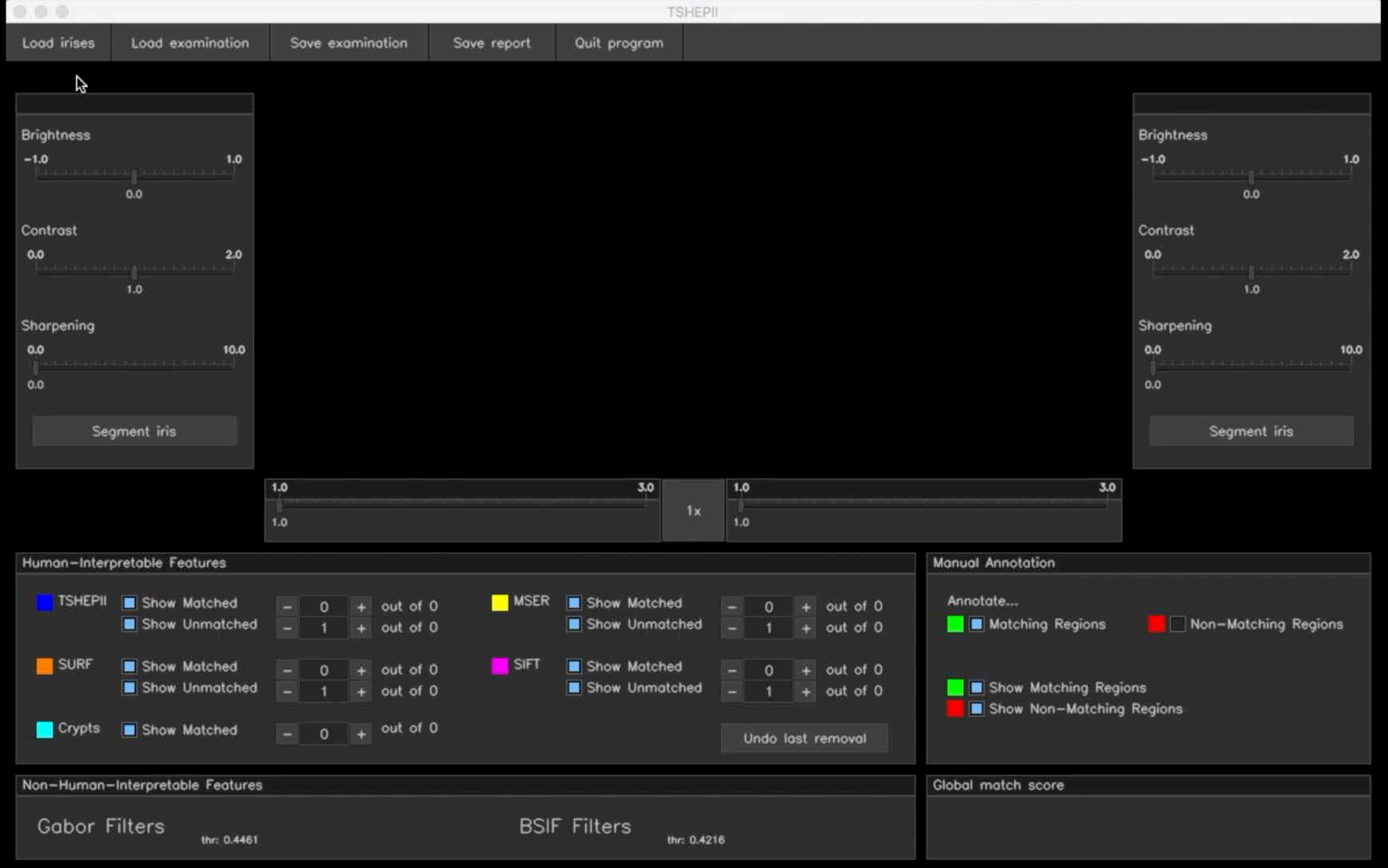
Biometric Systems

Enrollment



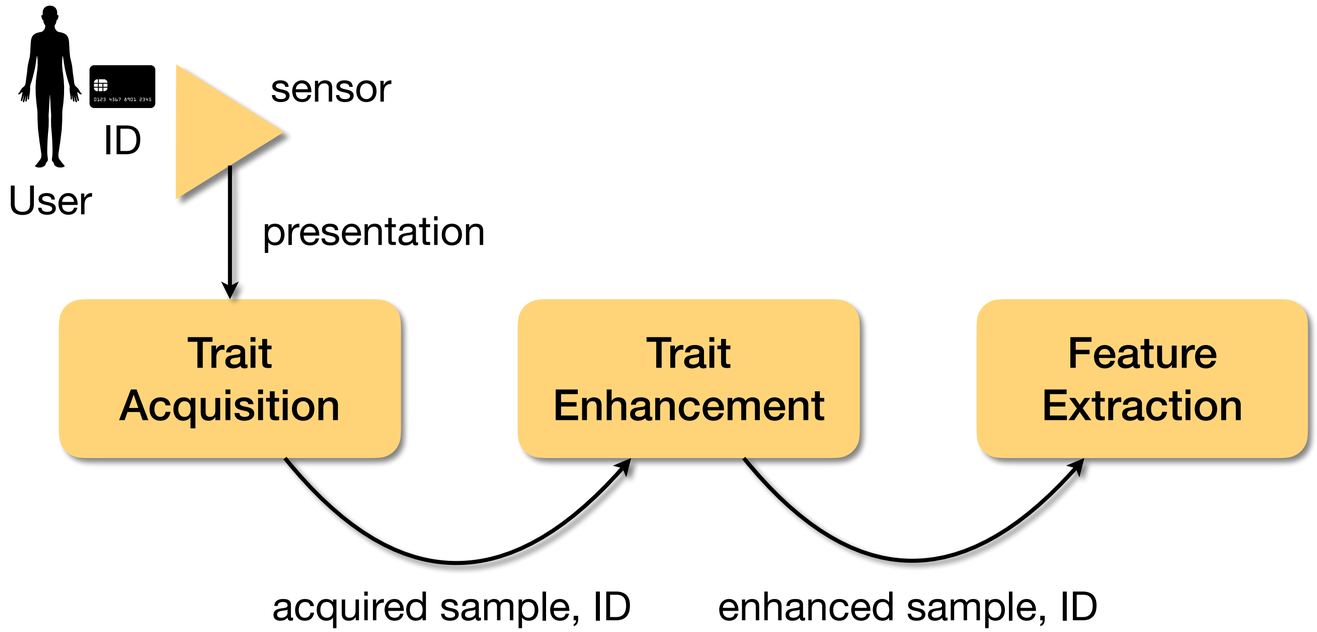
Trait Enhancement
Noise removal.
Operations to keep only **essential** information (consider universality, uniqueness, permanence, circumvention, and performance).


0.998
0.986
0.999


TSHEPII
Load irises
Load examination
Save examination
Save report
Quit program
Brightness
-1.0
1.0
0.0
Contrast
0.0
2.0
1.0
Sharpening
0.0
10.0
0.0
Segment iris
Brightness
-1.0
1.0
0.0
Contrast
0.0
2.0
1.0
Sharpening
0.0
10.0
0.0
Segment iris
1.0
3.0
1.0
1x
1.0
3.0
1.0
Human-Interpretable Features
TSHEPII
Show Matched
Show Unmatched
0
out of 0
1
out of 0
SURF
Show Matched
Show Unmatched
0
out of 0
1
out of 0
Crypts
Show Matched
0
out of 0
MSER
Show Matched
Show Unmatched
0
out of 0
1
out of 0
SIFT
Show Matched
Show Unmatched
0
out of 0
1
out of 0
Undo last removal
Manual Annotation
Annotate...
Matching Regions
Non-Matching Regions
Show Matching Regions
Show Non-Matching Regions
Non-Human-Interpretable Features
Gabor Filters
thr: 0.4461
BSIF Filters
thr: 0.4216
Global match score

Biometric Systems

Enrollment Modules

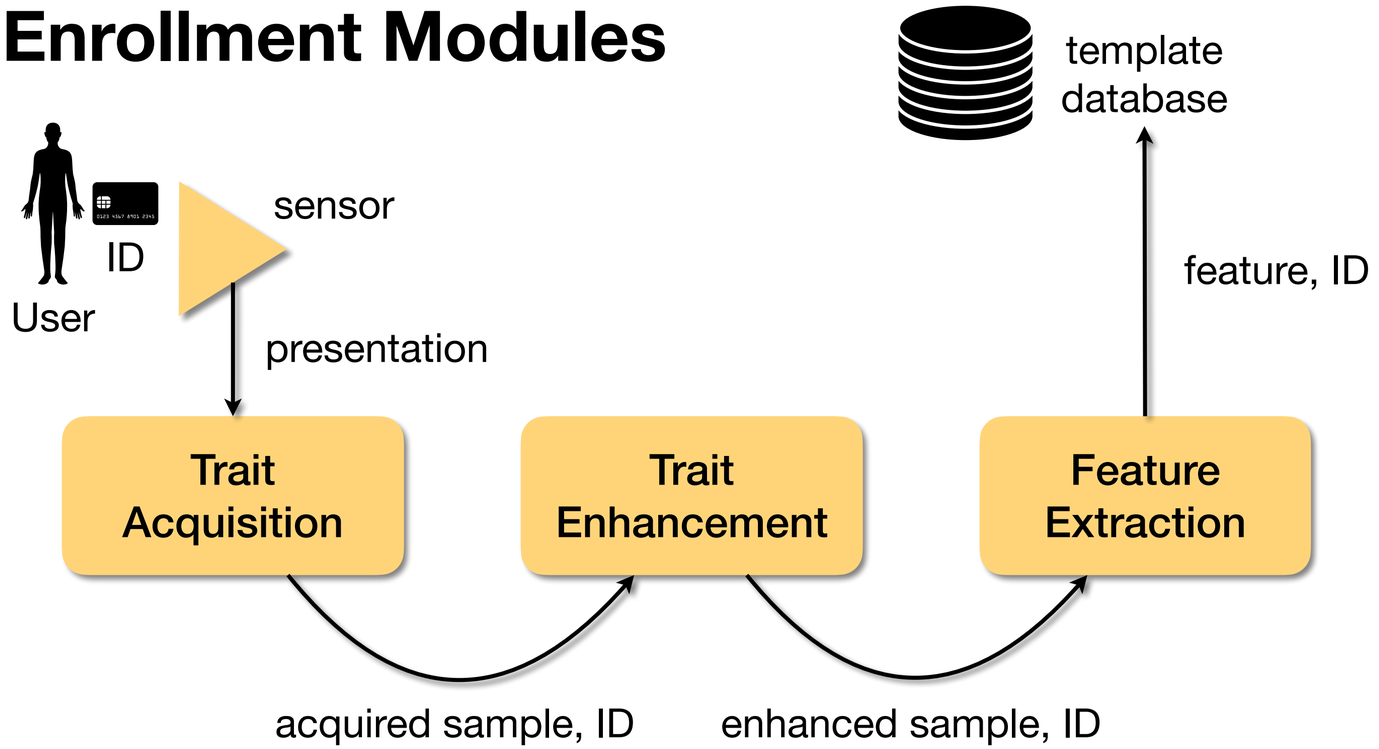


Feature Extraction
Compact but expressive digital representation of the trait.

Types
Handcrafted or **learned** with machine learning.
We'll see both cases.

Biometric Systems

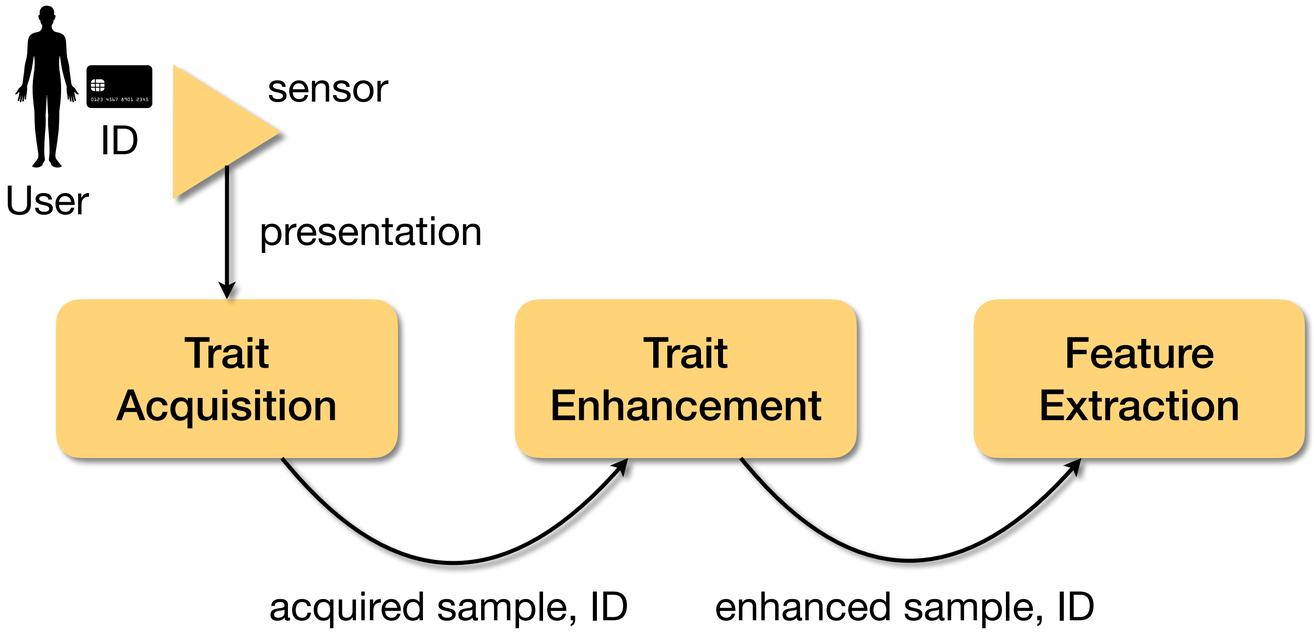
Enrollment Modules



Template Database
It inherits all the security and privacy issues from database systems.
Be careful with invasions, leaks, etc.

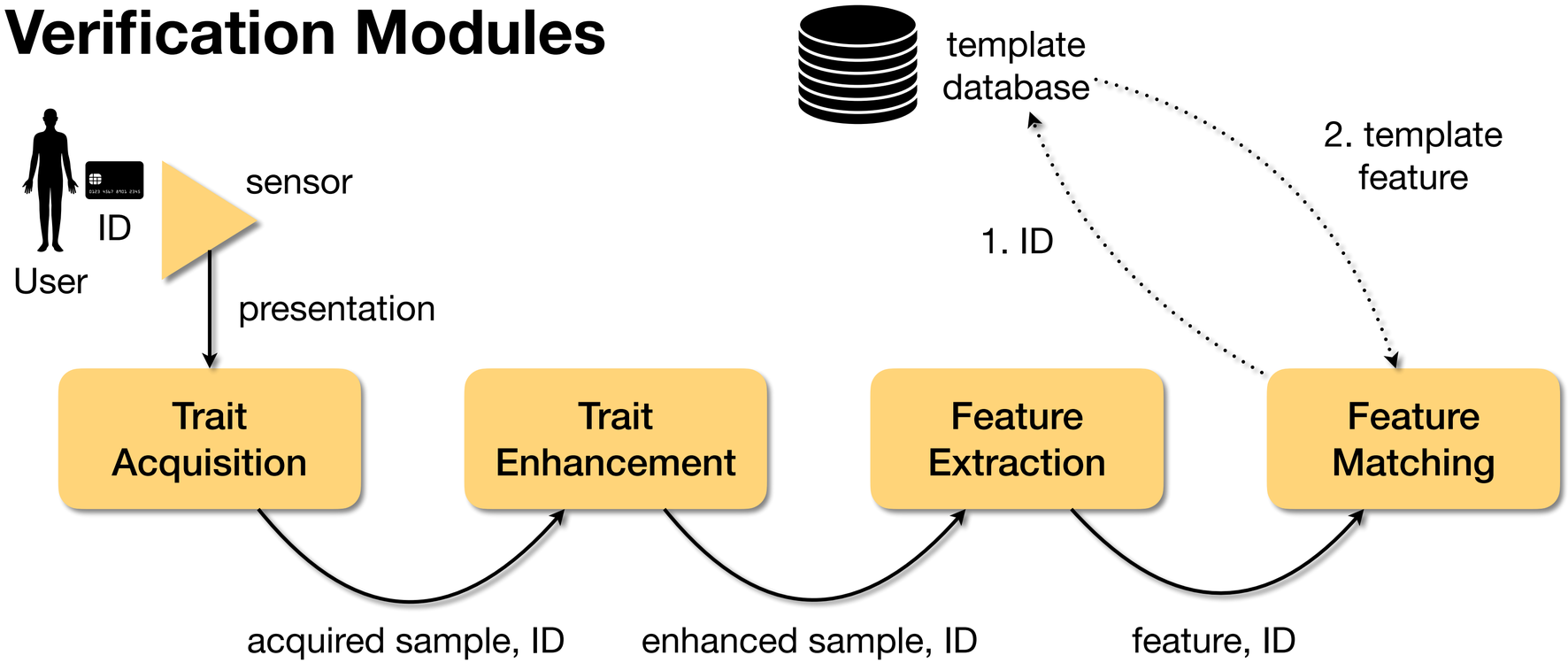
Biometric Systems

Verification Modules



Biometric Systems

Verification Modules



Feature Matching Comparison of **acquired** and **template** features.

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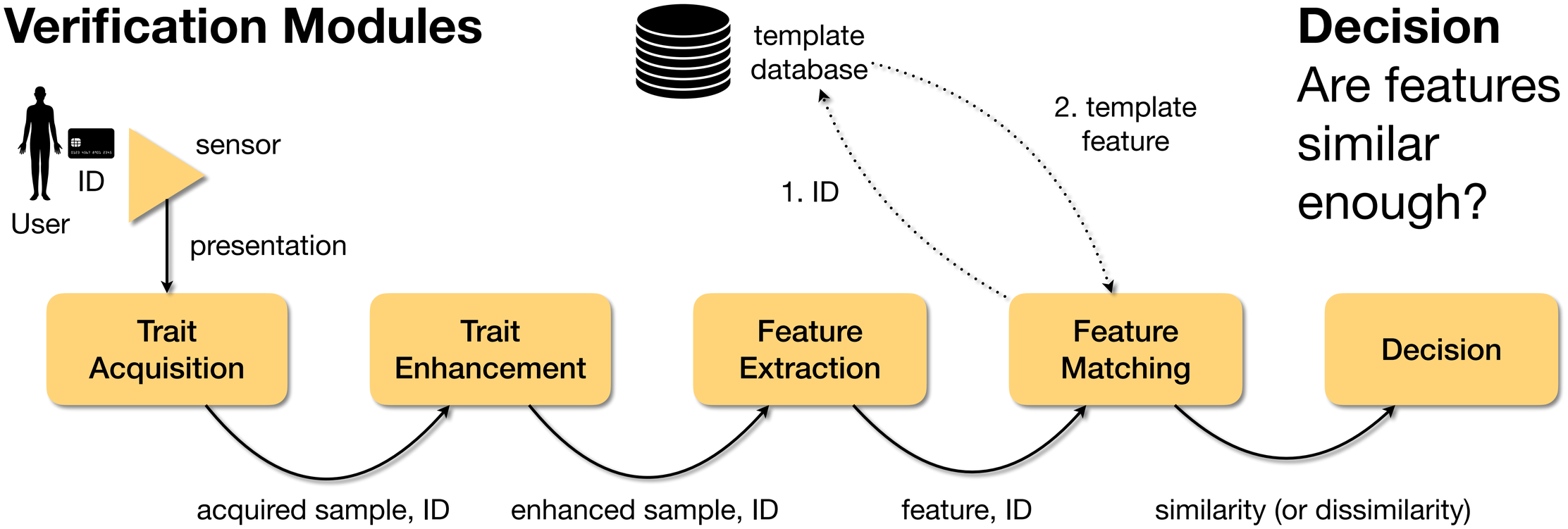
Biometric Systems

Verification Modules



Decision

Are features similar enough?

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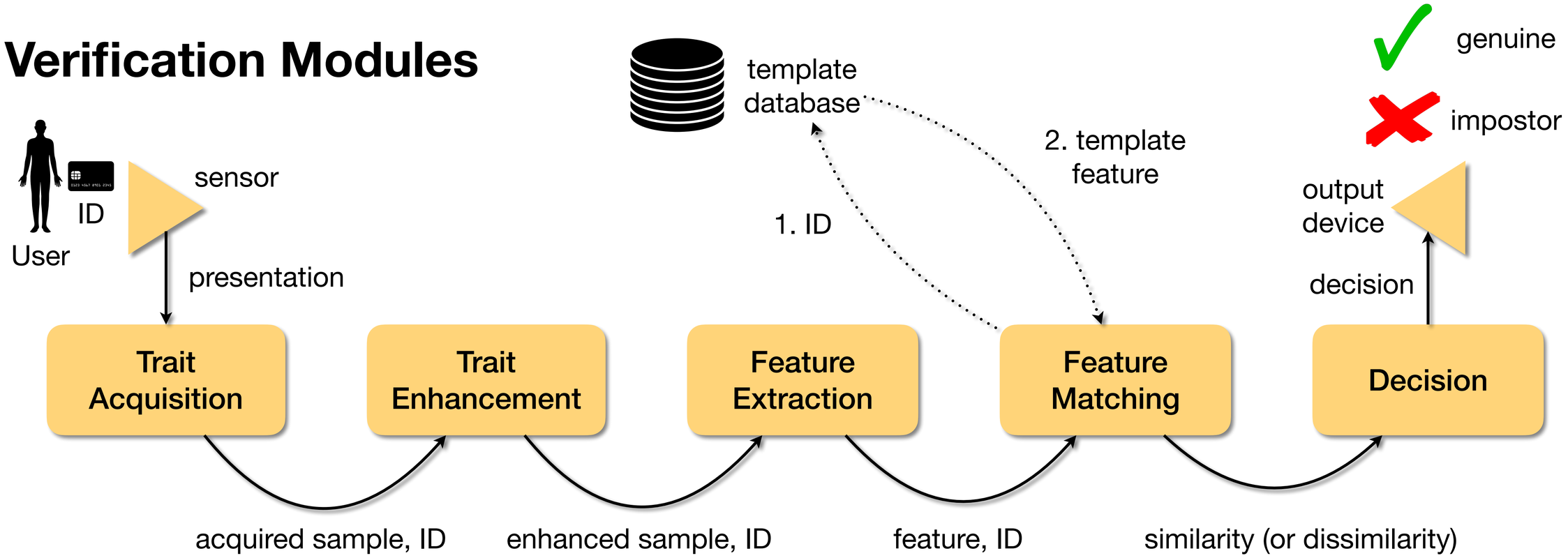
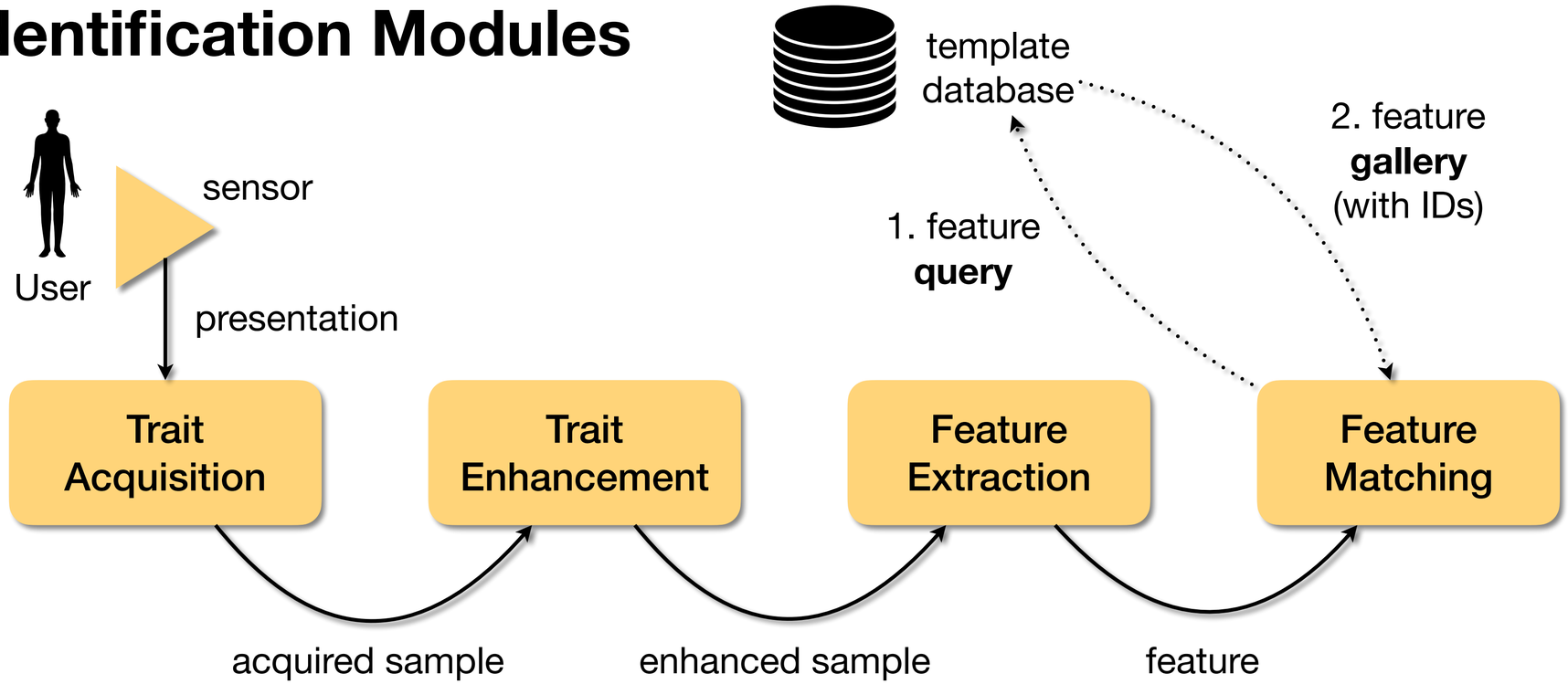
Biometric Systems



Biometric Systems

Identification Modules



Gallery
Closest template features to query.

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Biometric Systems

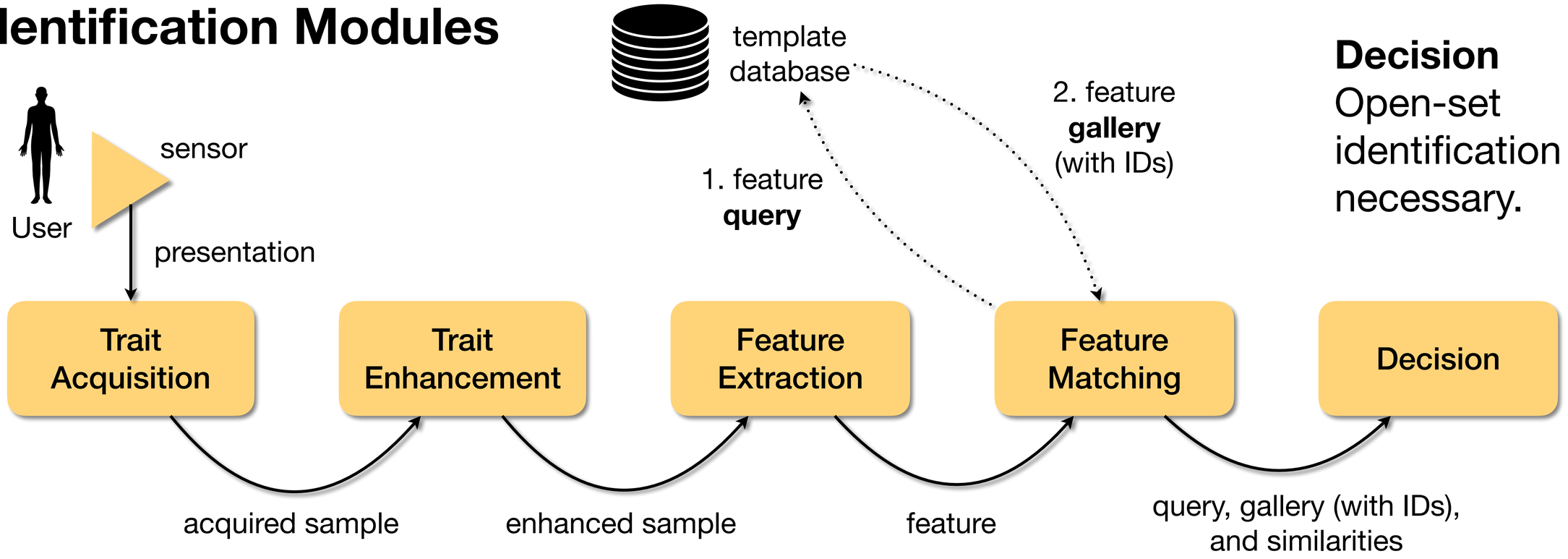
Query and Gallery Example

query

gallery

Biometric Systems

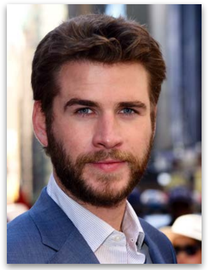
Identification Modules



Decision
Open-set identification is necessary.

Biometric Systems

Open-set vs. Closed-set Identification

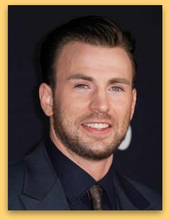


Query
(Liam Hemsworth)

Dataset

Robert Downey Jr.

Scarlet Johansson



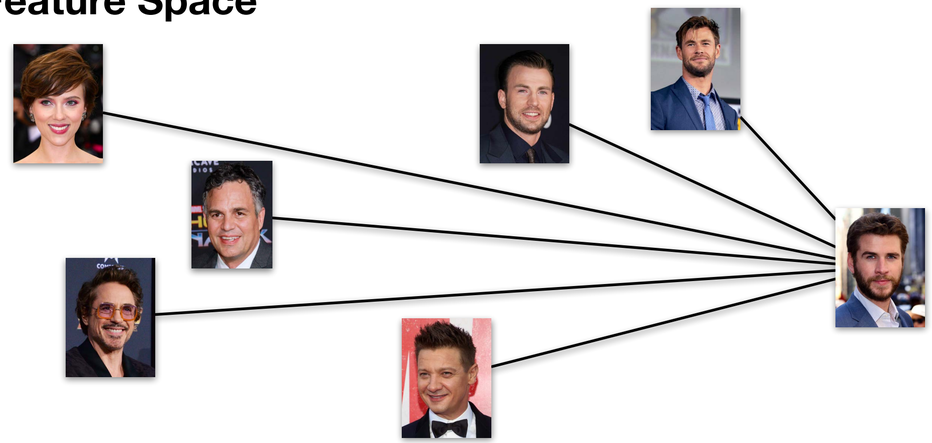
Chris Evans

Mark Ruffalo

Chris Hemsworth

Jeremy Renner

Feature Space



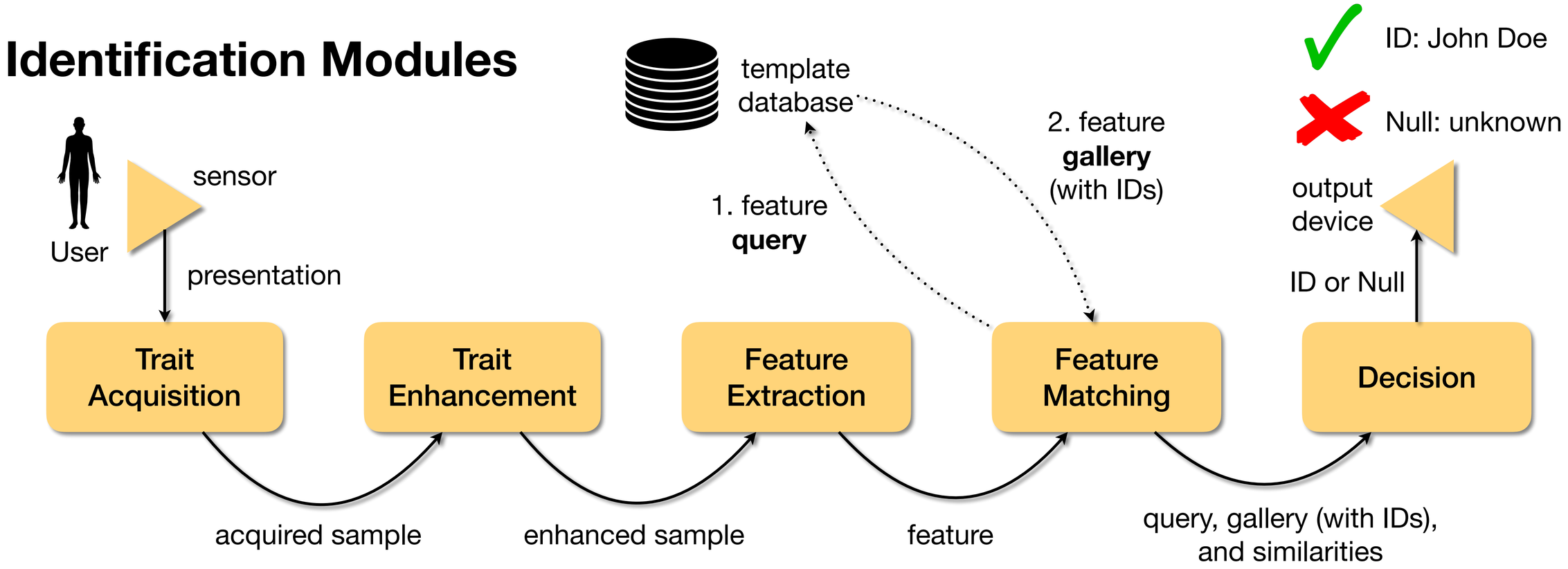
Closed Set

Output
This is Chris Hemsworth!

Open Set

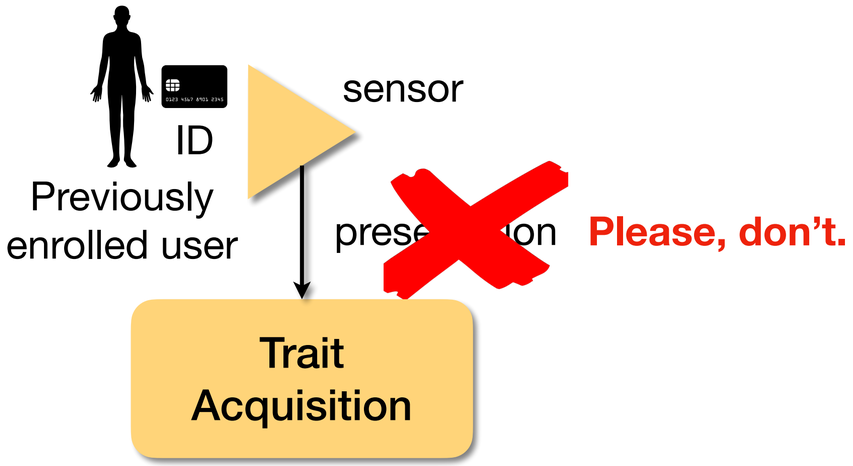
Output
I don't know this person!

Biometric Systems



Biometric Systems

Enrollment Revision

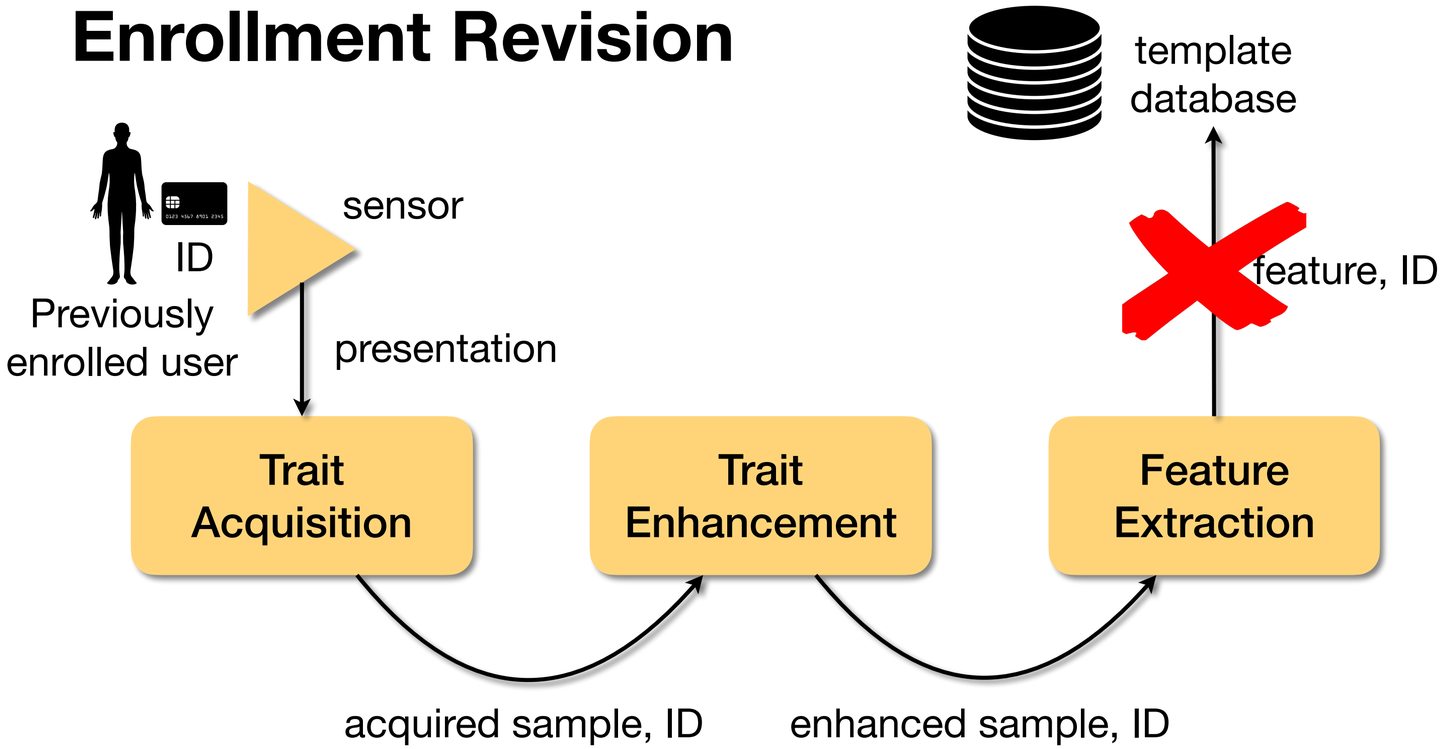


Attended operation?

"I'm seeing here in my notes that you are already enrolled."

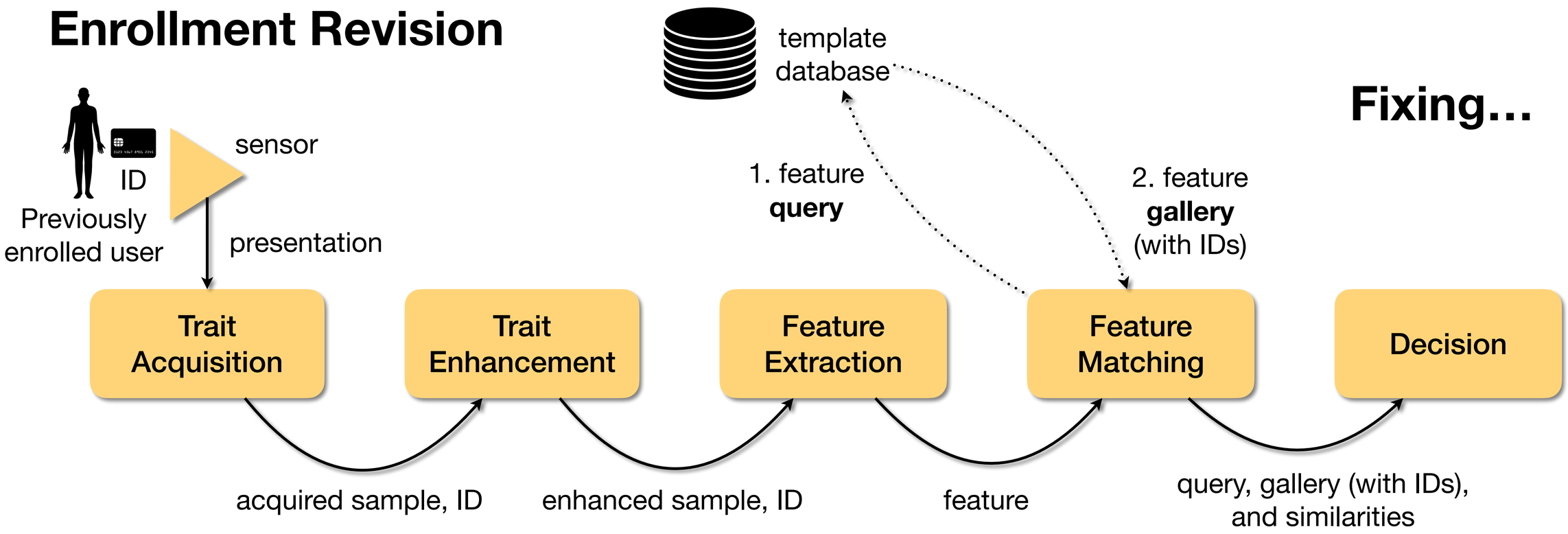
Biometric Systems

Enrollment Revision



Unattended operation?
The system must deal with re-enrollment attempts.

Biometric Systems



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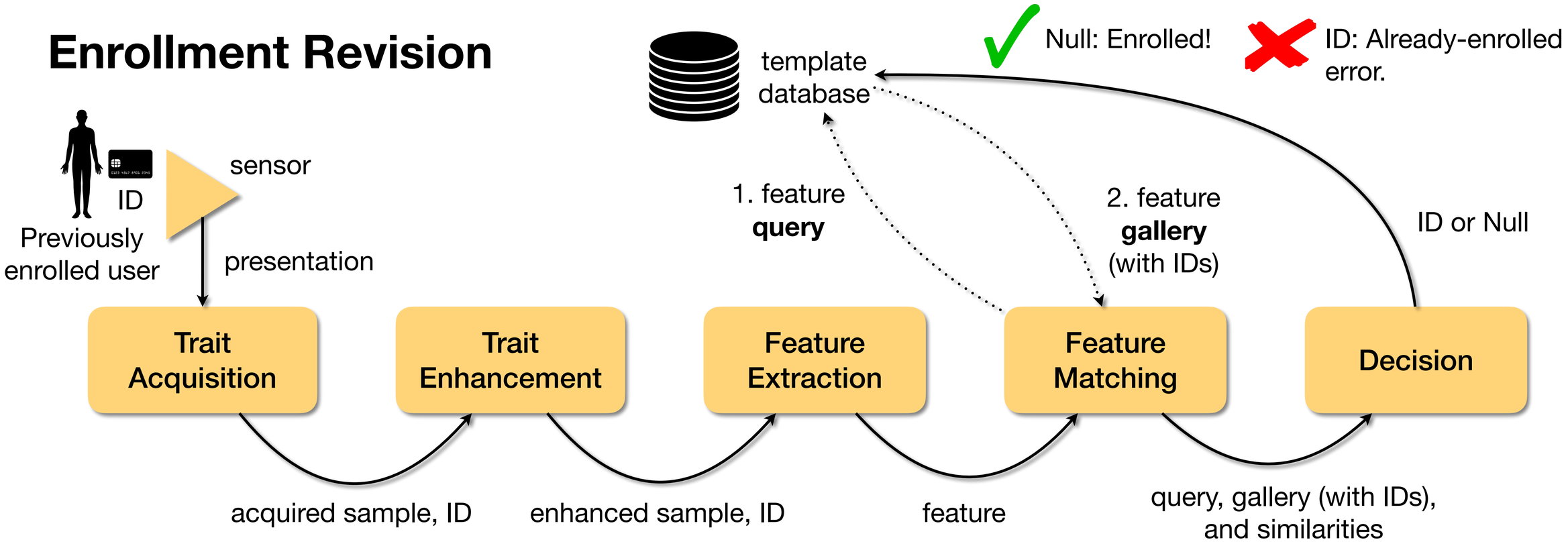
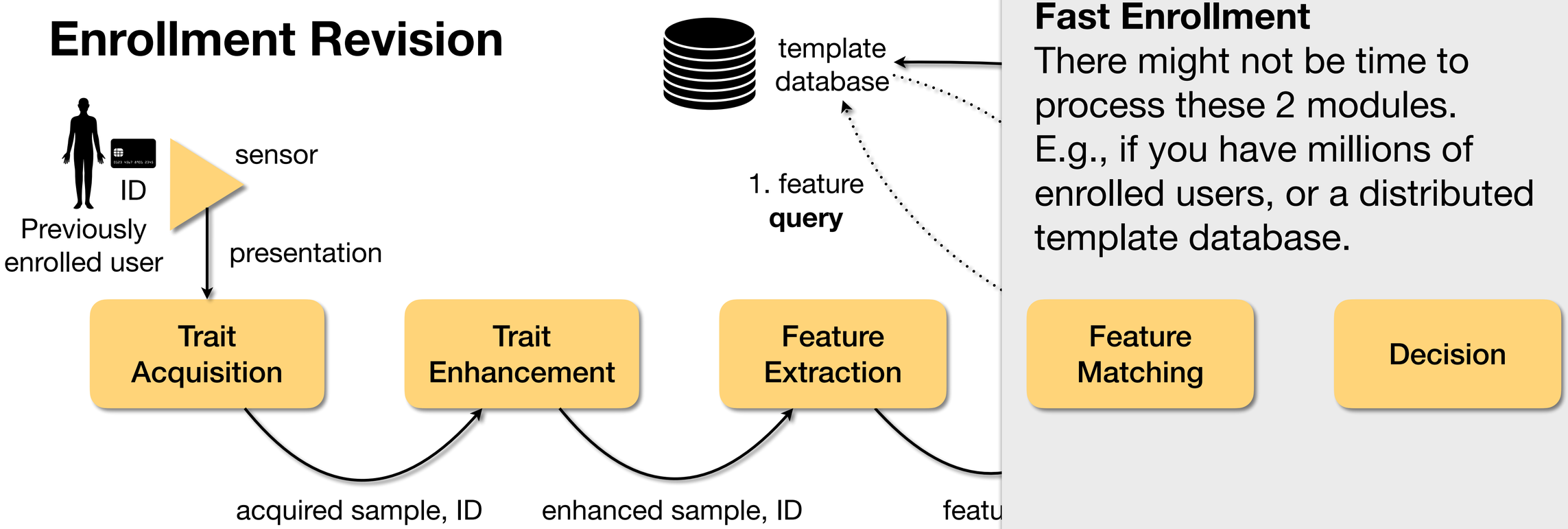
Biometric Systems



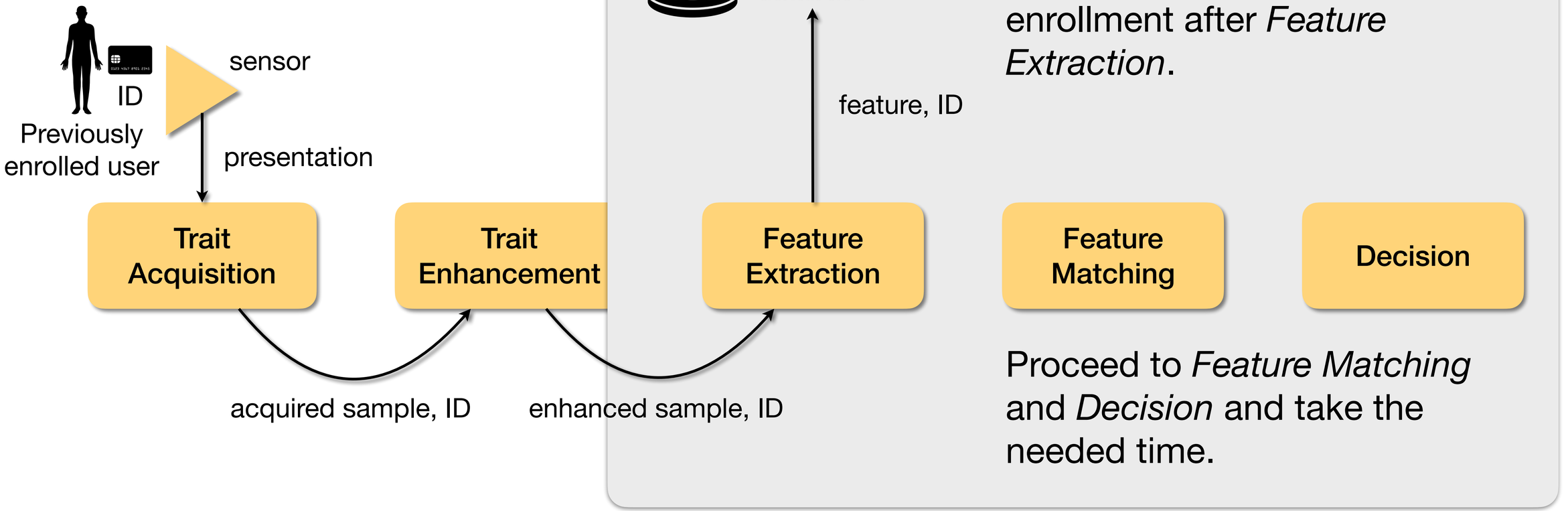
Biometric Systems



Fast Enrollment
There might not be time to process these 2 modules.
E.g., if you have millions of enrolled users, or a distributed template database.

Biometric Systems

Enrollment Revision

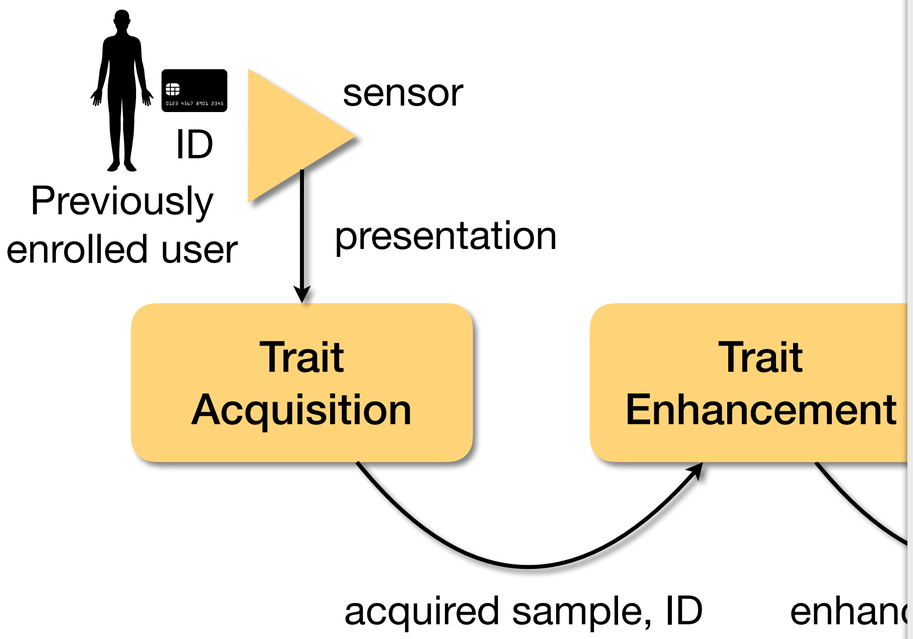


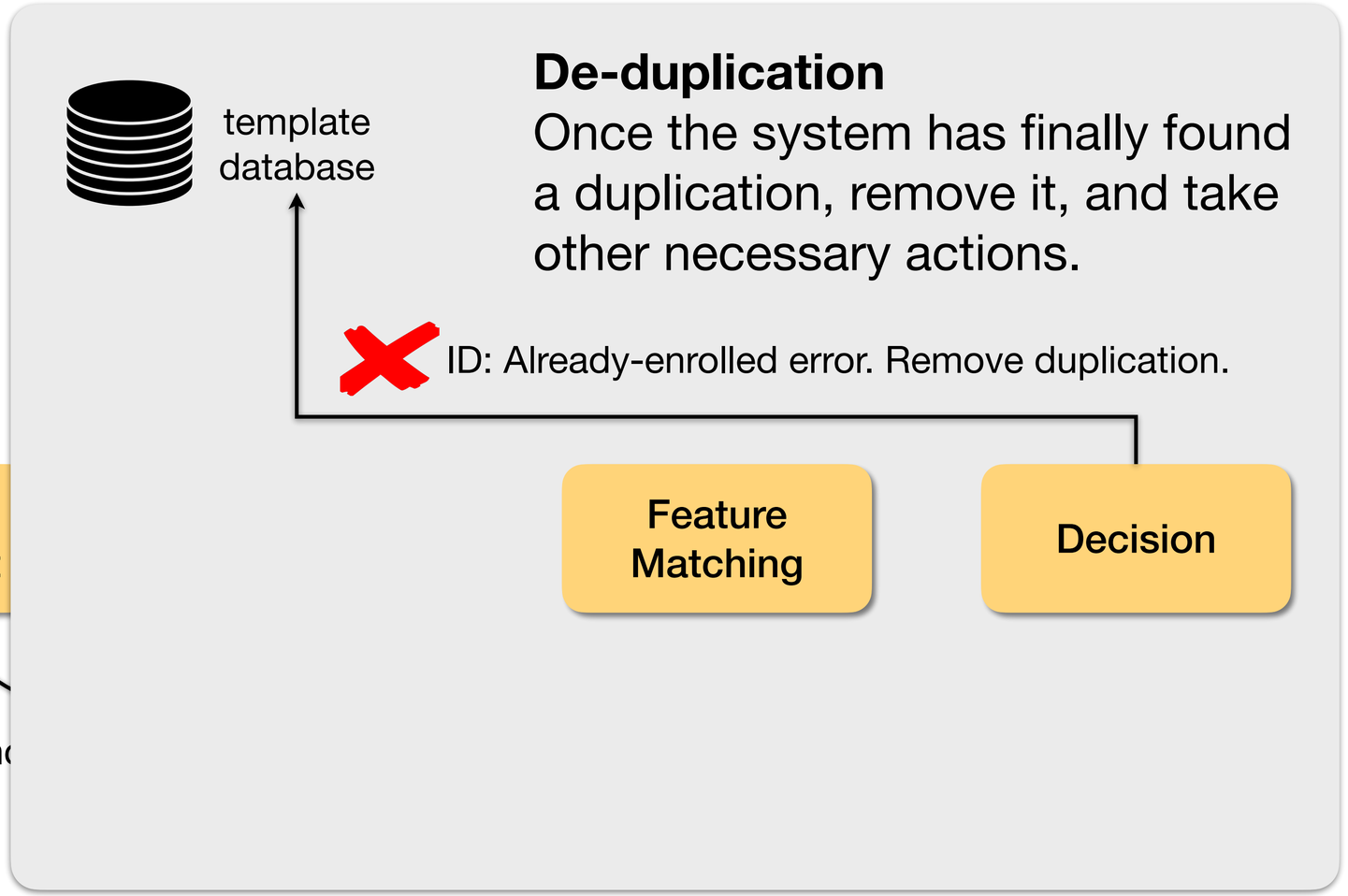
Fast Enrollment
Possible solution: conclude enrollment after *Feature Extraction*.

Proceed to *Feature Matching* and *Decision* and take the needed time.

Biometric Systems

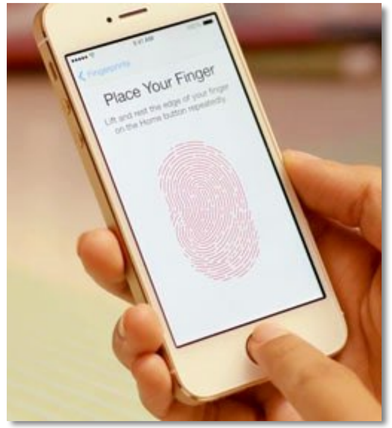
Enrollment Revision



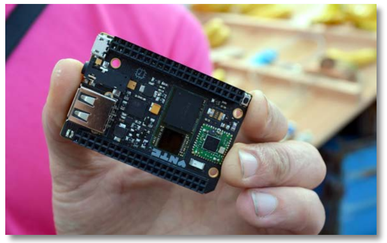


Biometric Systems

Deployment



From all modules integrated within single chips…



To disperse modules independently deployed in diverse platforms.

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Biometric Systems

What do we want to consider?
Things to consider when designing a Biometrics system, besides trait.

Cooperative or non-cooperative users? (1/5)
Do users want to be identified?

Don’t appeal to covert deployment.

Biometric Systems

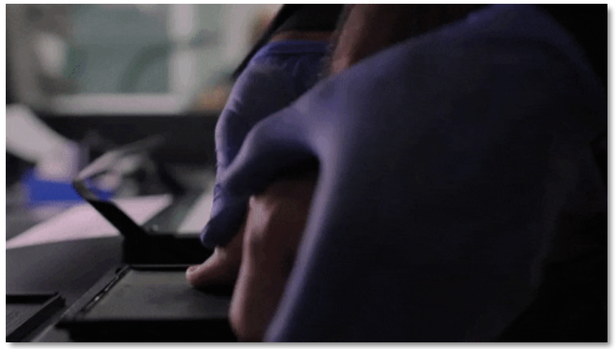
What do we want to consider?
Things to consider when designing a Biometrics system, besides trait.

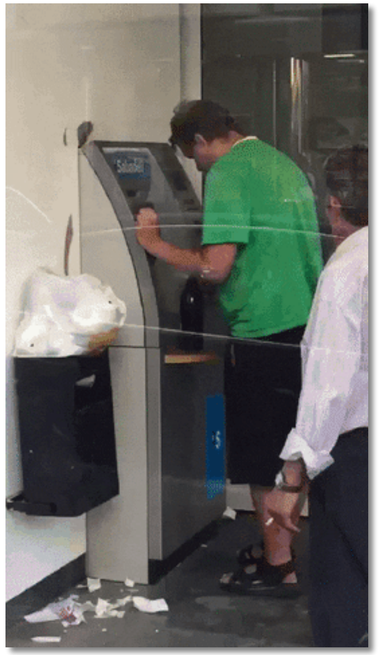
Habituated or non-habituated users? (2/5)
Do users interact with the system frequently or sporadically?

Biometric Systems

What do we want to consider?
Things to consider when designing a Biometrics system, besides trait.

Attended or unattended operation? (3/5)
Will somebody be helping users?

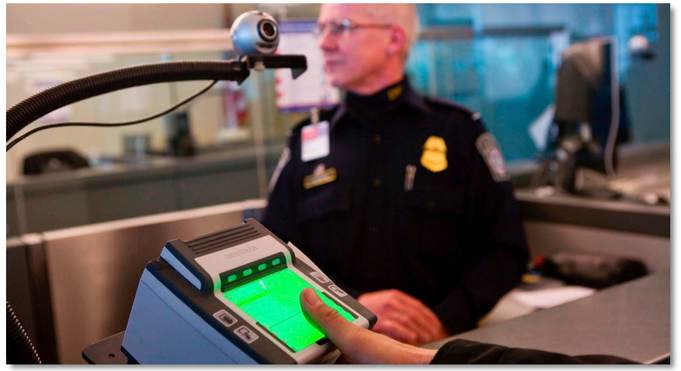


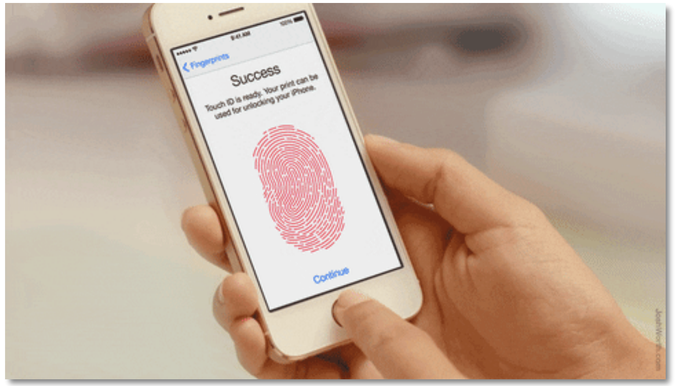


Biometric Systems

What do we want to consider?
Things to consider when designing a Biometrics system, besides trait.

Controlled or uncontrolled environment? (4/5)
How do the environmental conditions change? (temperature, illumination, etc.)





Biometric Systems

What do we want to consider?
Things to consider when designing a Biometrics system, besides trait.

What are the computational requirements? (5/5)
Consider memory footprint, processing time, response time, and system availability.

Biometric Systems

What do we want to avoid?

❌ **Covert deployment**
Users must be aware of the Biometric system collecting their data.
Respect their privacy.

❌ **No data confidentiality**
Collected data must be confidential. Avoid function creep.

❌ **Unsafe system**
We will get to know threats (attacks) that may harm a system's integrity.

Biometric System Errors

Denial of Access (1/3)

Verification
Jane Doe: Here, I’m Jane Doe.
System: No, you’re not.

Identification
Jane Doe: Here, my fingerprints.
System: I don’t know you.

Biometric System Errors

Denial of Access (1/3)

Possible Causes
Intrinsic failure: intra-user trait variation,
due to different sensors, hardware malfunction, pose, illumination,
make-up, aging, illness, cosmetic surgeries, etc.

Adversarial attack: malicious alteration of
template database, etc.

Biometric System Errors

Intrusion (2/3)

Verification
Jane Doe: Here, I'm Jane Fonda.
System: Welcome, Jane Fonda!

Identification
Jane Doe: Here, my fingerprints.
System: Welcome, Jane Fonda!

https://www.wired.com/story/10-year-old-face-id-unlocks-mothers-iphone-x/

Biometric System Errors

Intrusion (2/3)

Possible Causes
Intrinsic failure: inter-user high similarity, due to low trait uniqueness, poor trait capture, etc.

Adversarial attack:
impersonation, spoofing, etc.

impersonation

spoofing

Biometric System Errors

Repudiation (3/3)

Verification
Jane Doe: See, I’m not Jane Doe.
System: Yeah, you’re right.

Identification
Jane Doe: Here, my fingerprints.
System: Yeah, I don’t know you.

Biometric System Errors

Repudiation (3/3)

Possible Causes
Intrinsic failure: hardware malfunction, intra-user trait variation.

Adversarial attack: obfuscation.

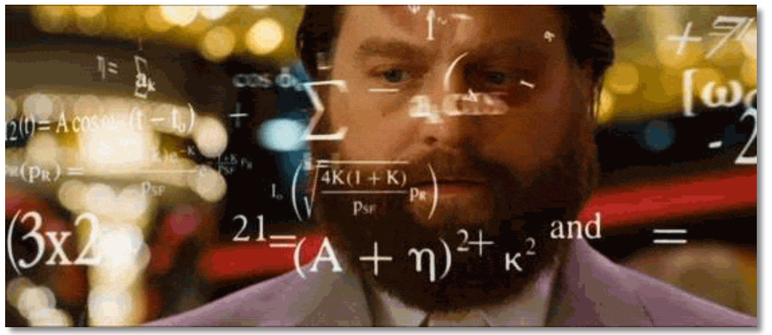
obfuscation

Biometric System Errors

Math Model
Objective definition of 2 events:

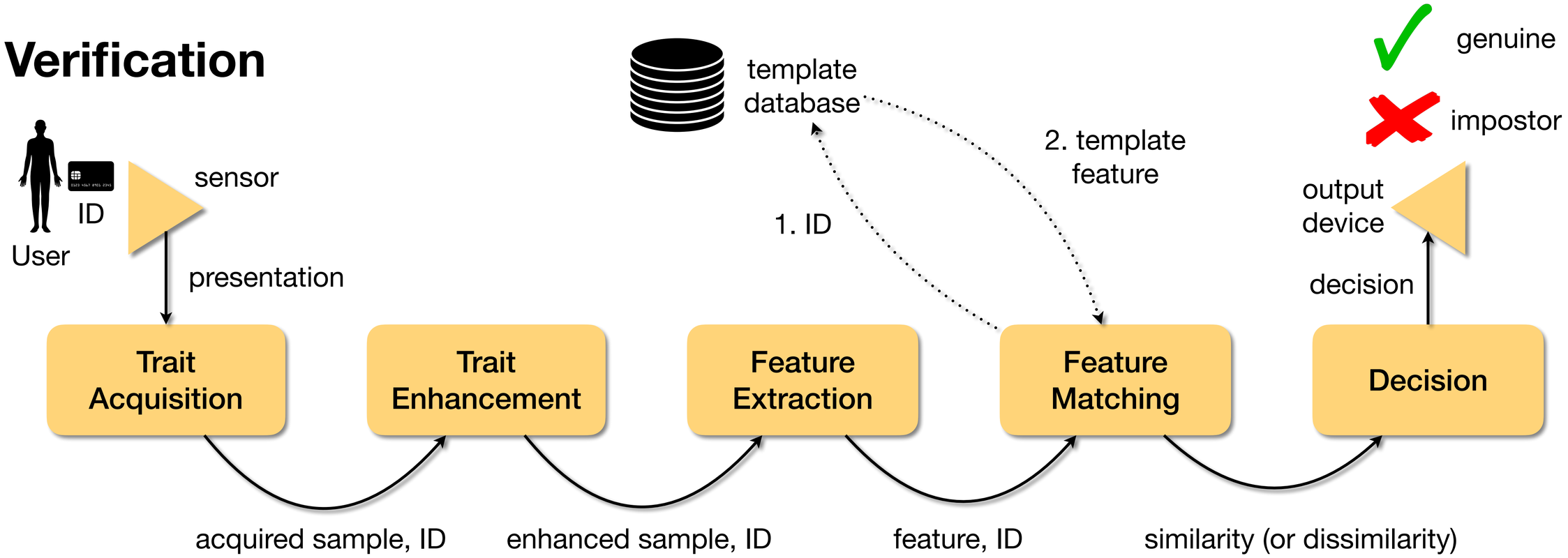
1. False Non-Match (FNM)
A comparison of two features of the same individual should lead to a match, but it led to a non-match.
It causes either a denial of access or helps repudiation.

2. False Match (FM)
A comparison of two features from different individuals should lead to a non-match, but it led to a match.
It helps an intrusion.

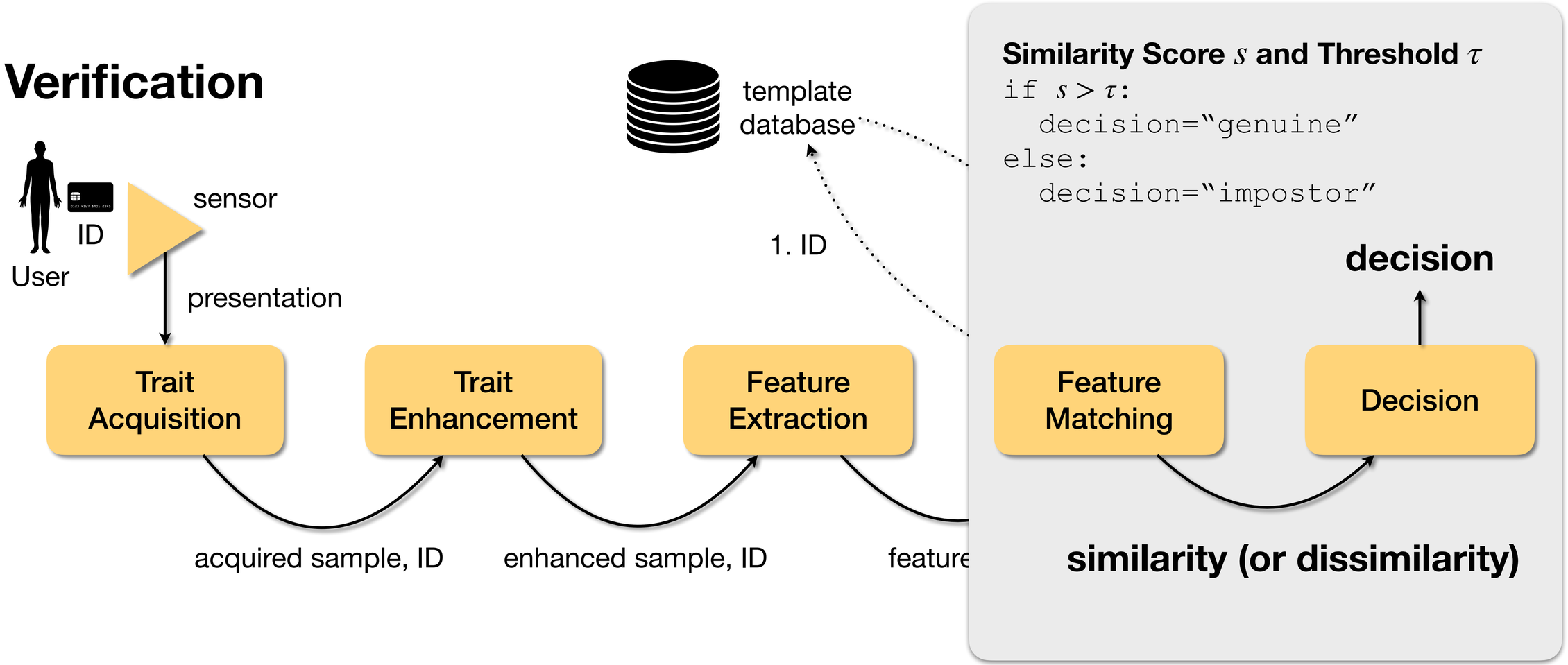


Let's see how to compute them!

Metrics



Metrics



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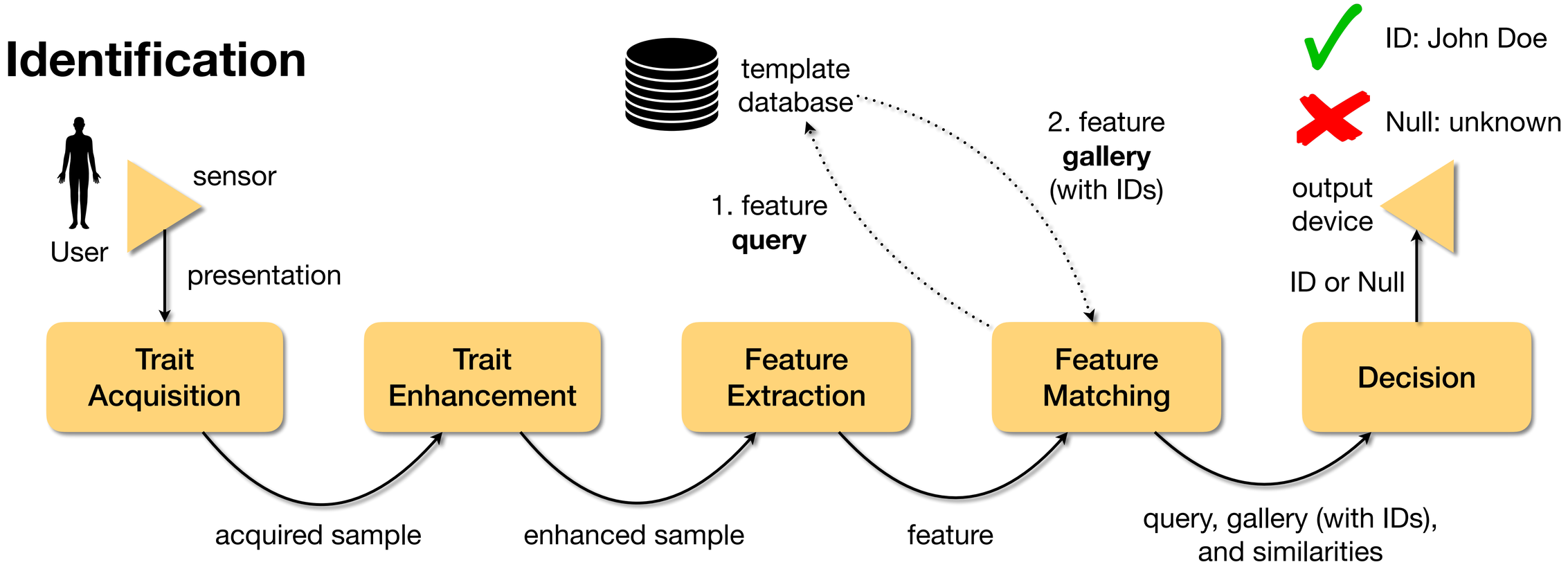
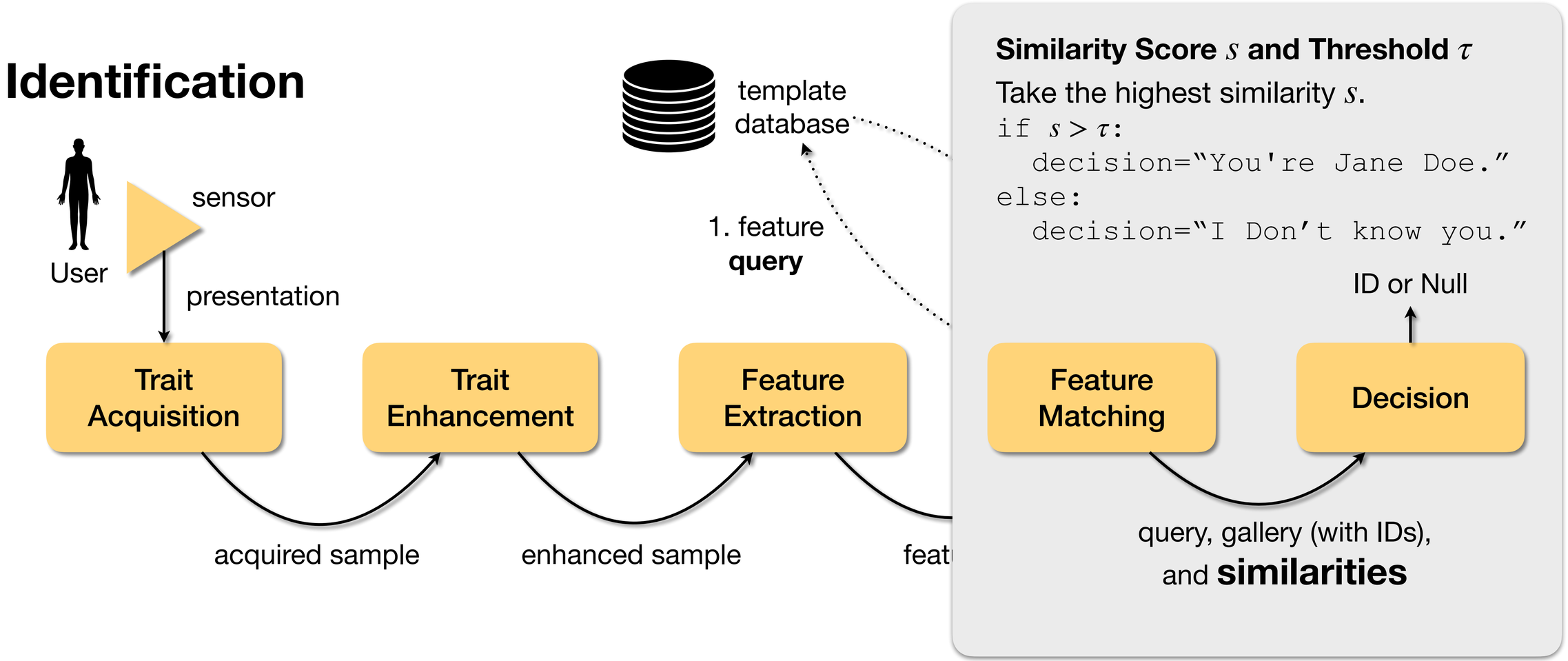
Metrics



Metrics



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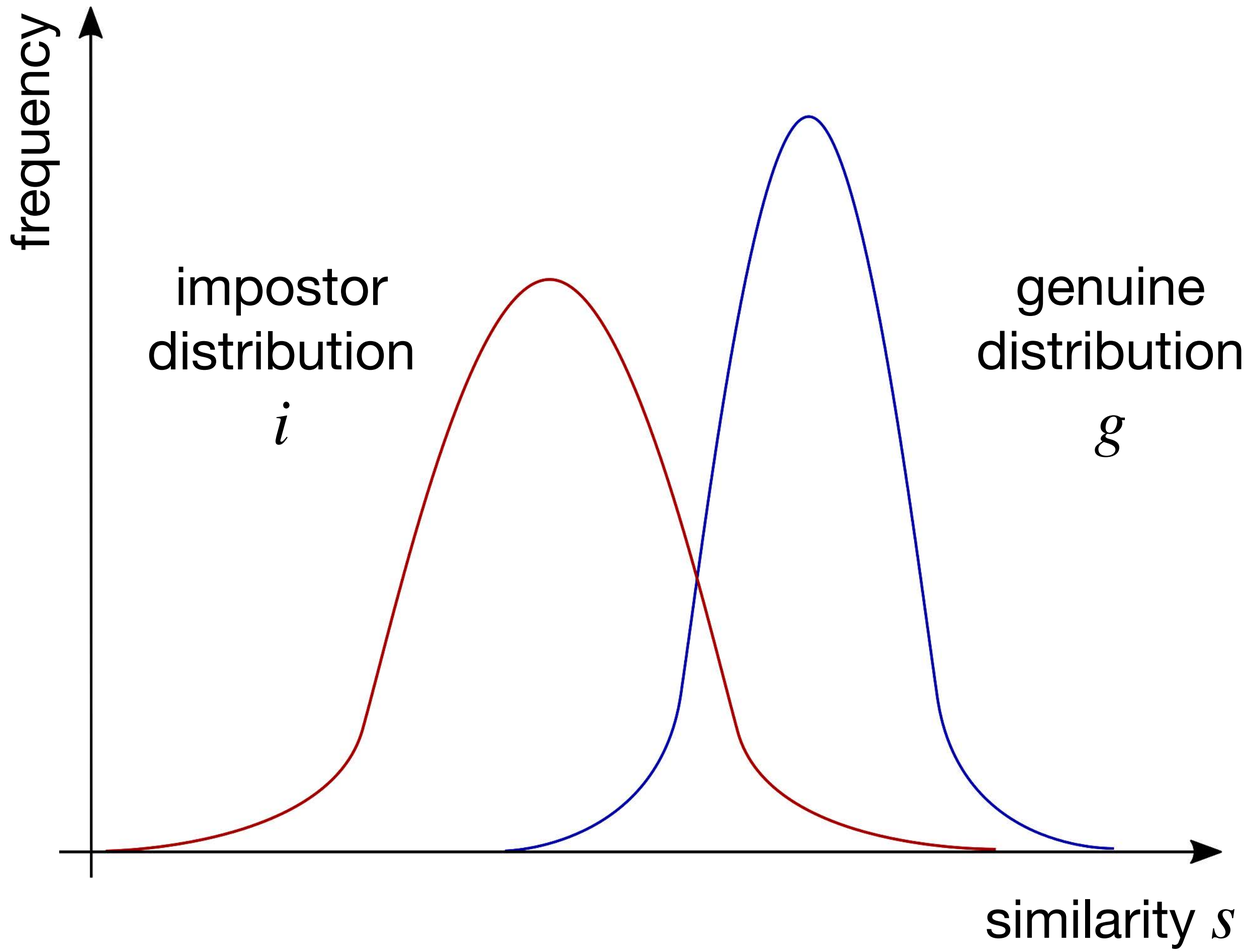
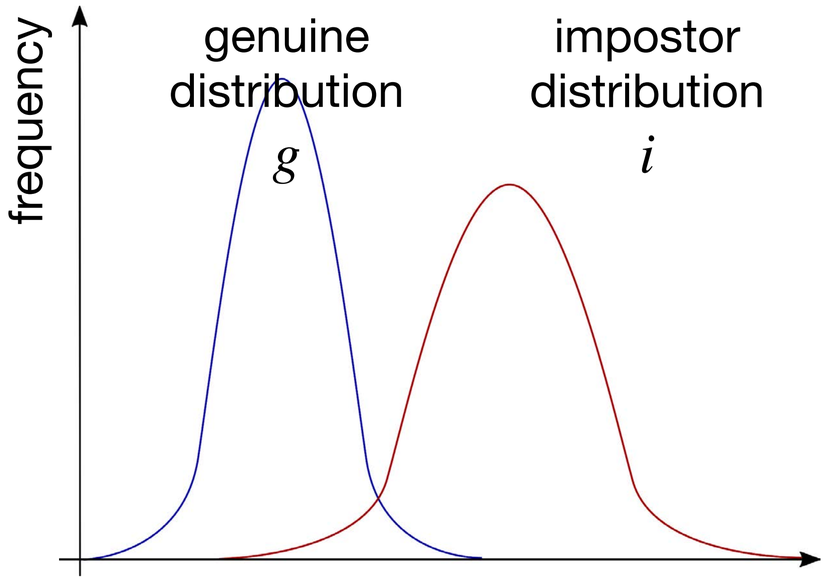
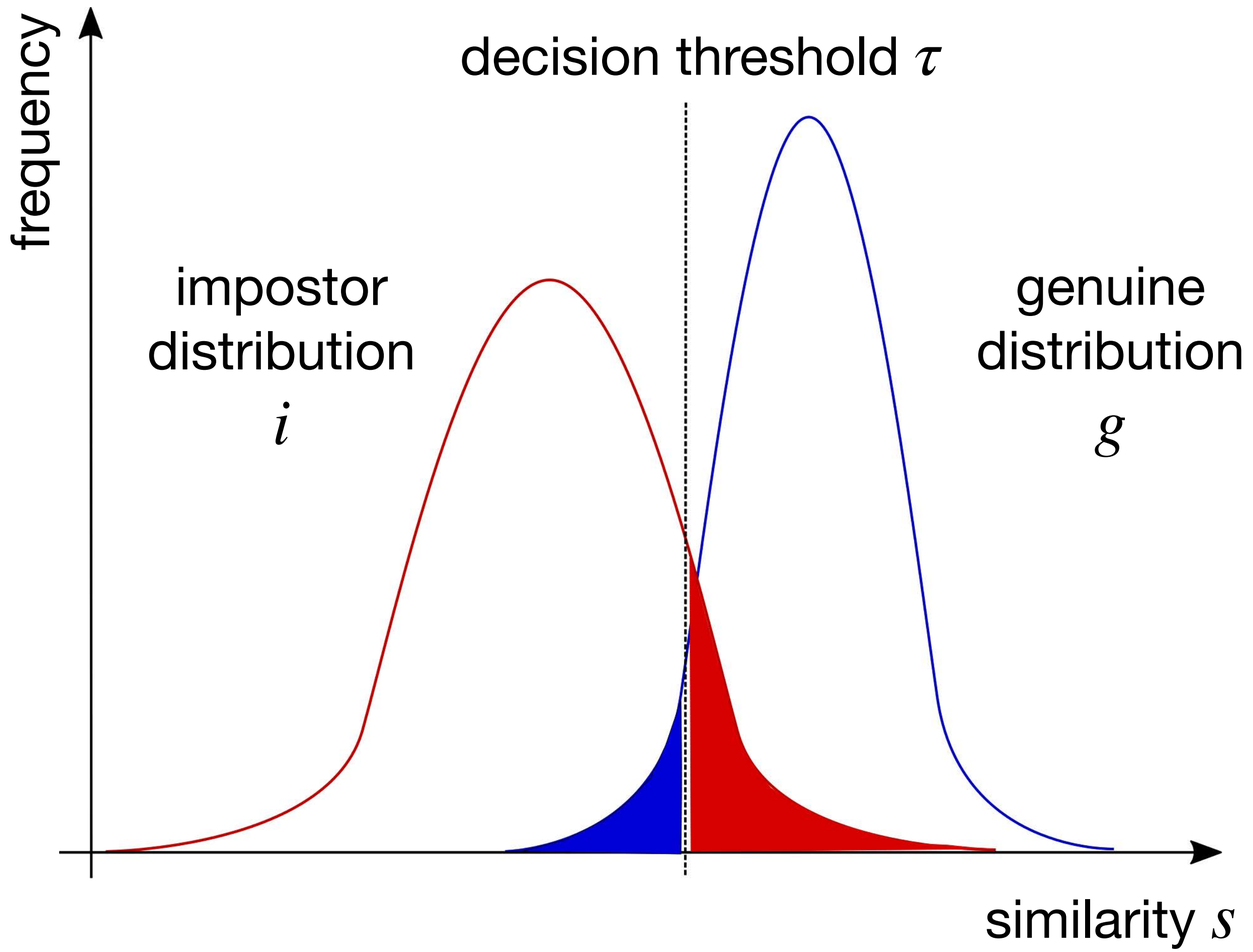
Metrics



In case of distances…



Metrics



$$FNM(\tau) = \int_{-\infty}^{\tau} g(s)\ ds$$

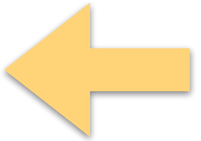
$$FM(\tau) = \int_{\tau}^{\infty} i(s)\ ds$$

Metrics

In Practice

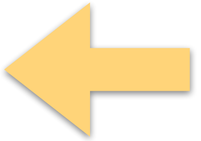
False Non-Match Rate (FNMR) and False Match Rate (FMR)

$$FNMR(\tau) = \frac{\#(false\ nonmatches\ for\ \tau)}{\#(genuine\ comparisons)}$$



$$FNM(\tau) = \int_{-\infty}^{\tau} g(s)\ ds$$

$$FMR(\tau) = \frac{\#(false\ matches\ for\ \tau)}{\#(impostor\ comparisons)}$$



$$FM(\tau) = \int_{\tau}^{\infty} i(s)\ ds$$

Metrics

In Practice

False Non-Match Rate (FNMR) and False Match Rate (FMR)

$$FNMR(\tau) = \frac{\#(false\ nonmatches\ for\ \tau)}{\#(genuine\ comparisons)}$$

How many of the genuine comparisons are wrongly computed by the system?

$$FMR(\tau) = \frac{\#(false\ matches\ for\ \tau)}{\#(impostor\ comparisons)}$$

How many of the impostor comparisons are wrongly computed by the system?

Metrics

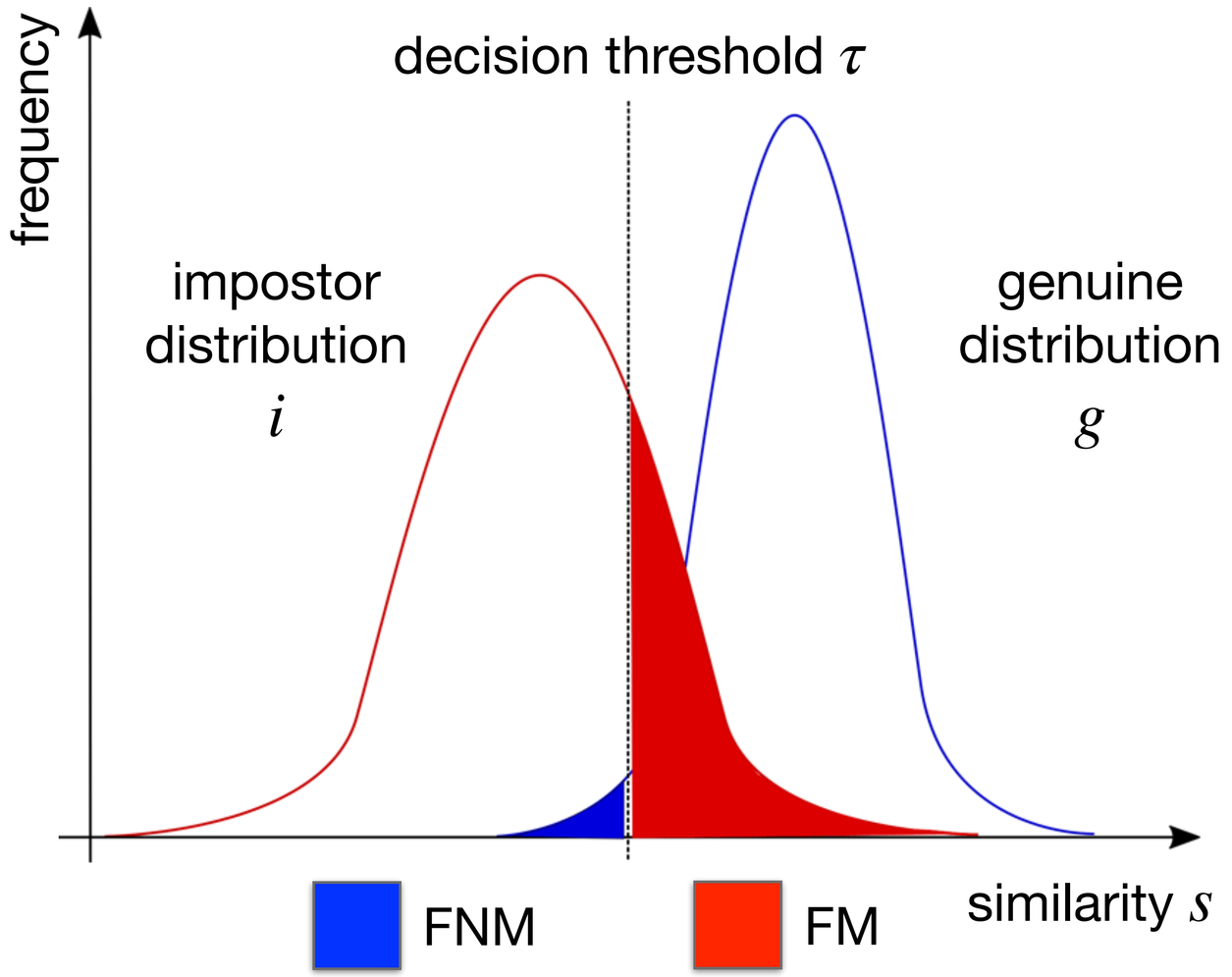
In Practice
Interpretation of *R values.

Suppose a face recognition system with FMR=0.1%
FMR=0.001, one error in every 1K comparisons.
Is it good?

Suppose the Newark airport
5K people per hour, 14h per day (70K people per day)
Suppose a suspect watch list with 100K people: 7 billion comparisons per day.
Average number of false matches per day: 7 million people to double check every day.

Terrorist watch list in 2016: 1,8 million people

Metrics



What is the impact of changing the decision threshold?

The larger the value of τ:
The larger the value of FNM;
The smaller the value of FM.

FNM and FM are inversely proportional.

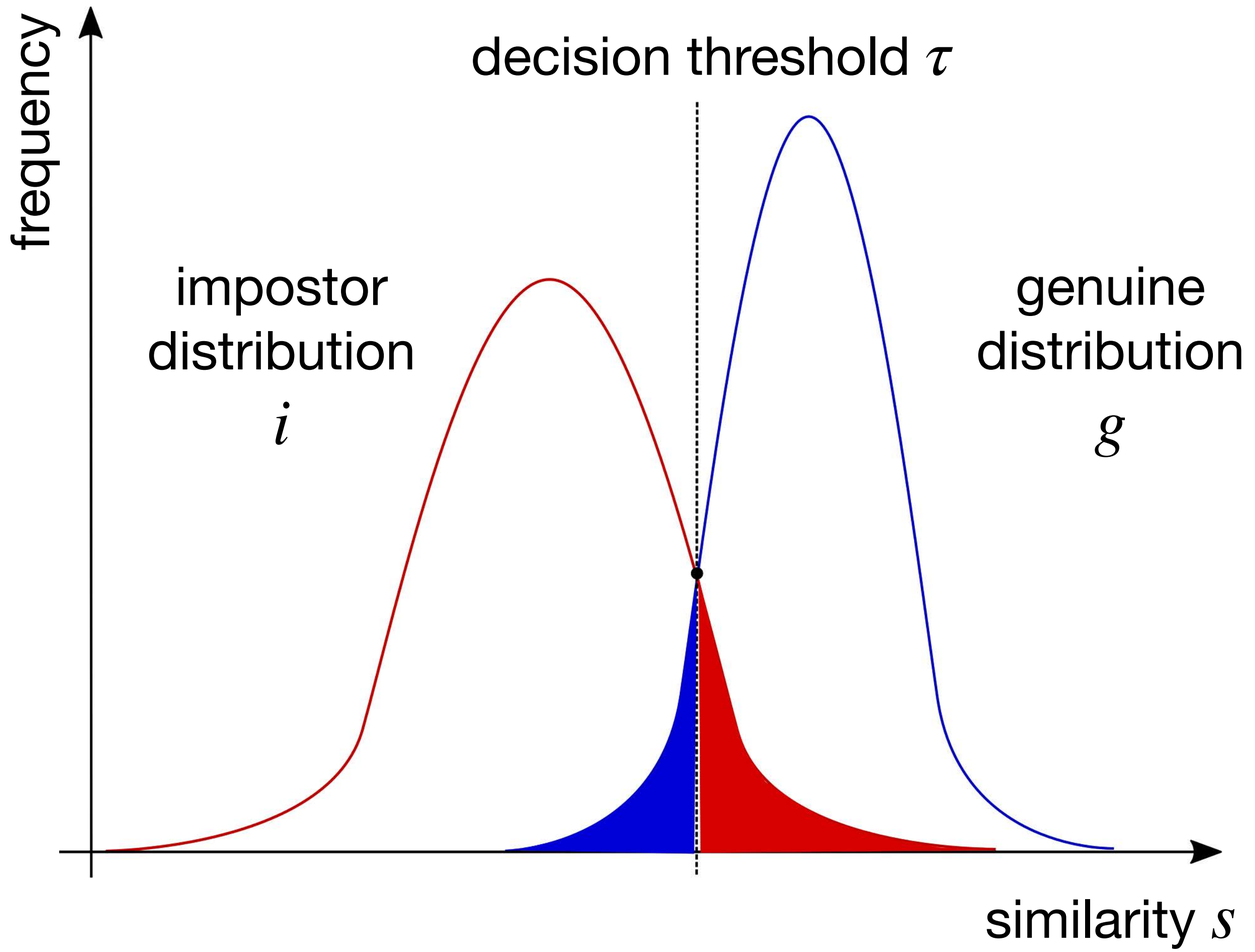
Metrics

What to choose?

Small FNMR
Suitable to avoid denial of access
and repudiation.
Increases intrusion probability, though.

Small FMR
Suitable to avoid intrusion.
Increases denial of service and
repudiation probability, though.

Metrics



What to choose?

Equal Error Rate (EER)
Common practice.
Pick the threshold where FNMR = FMR.

Metrics

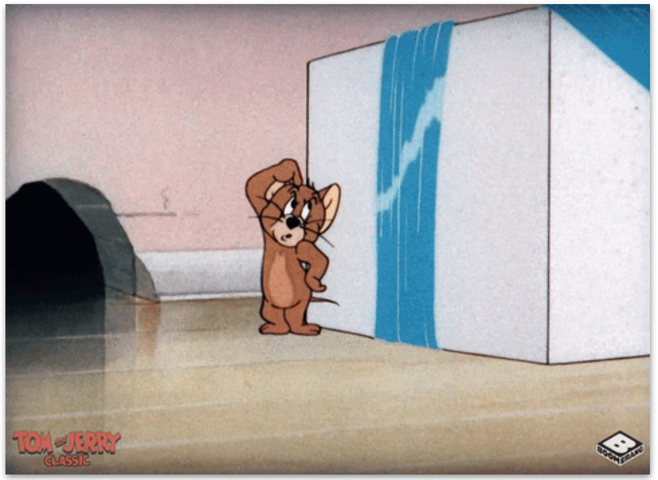
How to compare two different systems?
Biometric systems *A* and *B.*

Compare both systems' FNMR and FMR at EER (1/3)
Take the one with smaller FNMR and FMR values.

Metrics

How to compare two different systems?
Biometric systems *A* and *B.*

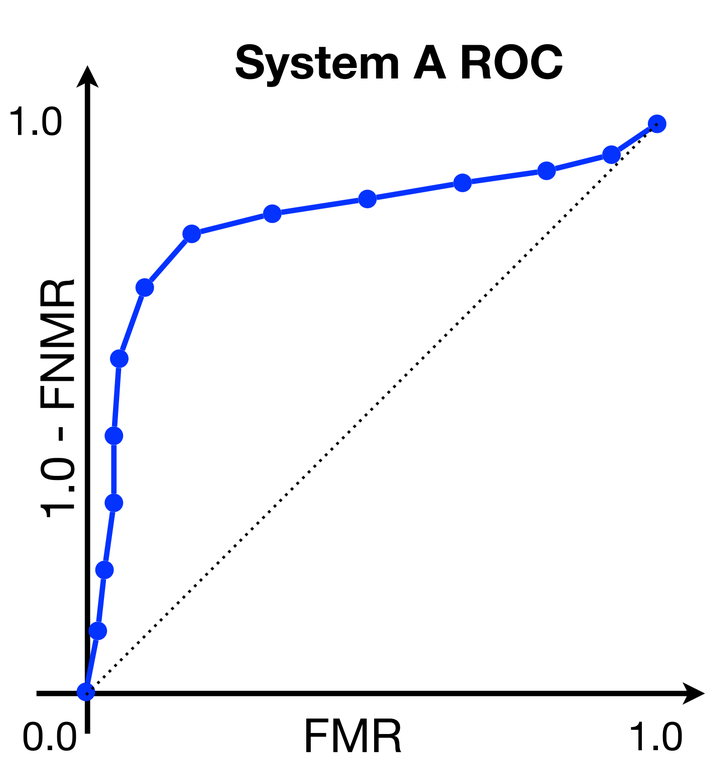
Use a Receiver Operating Characteristic (ROC) curve (2/3)

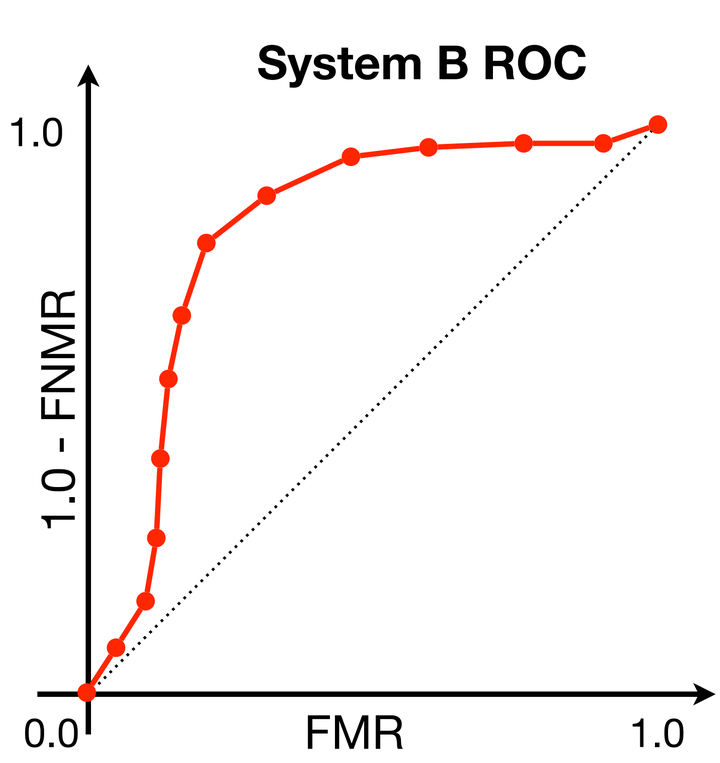


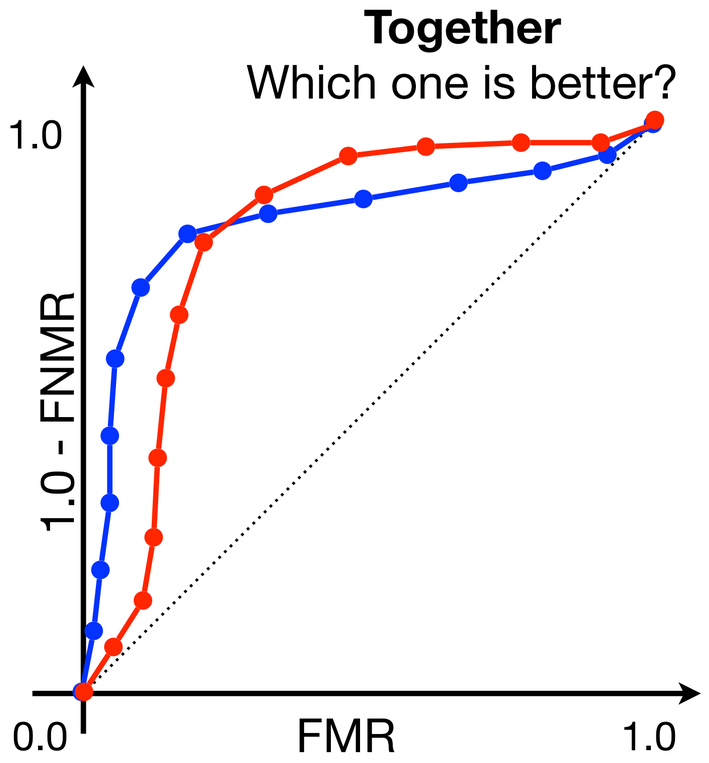
Metrics

How to compare two different systems?
Biometric systems *A* and *B.*

Compute FMR and FNMR for a variety of thresholds.

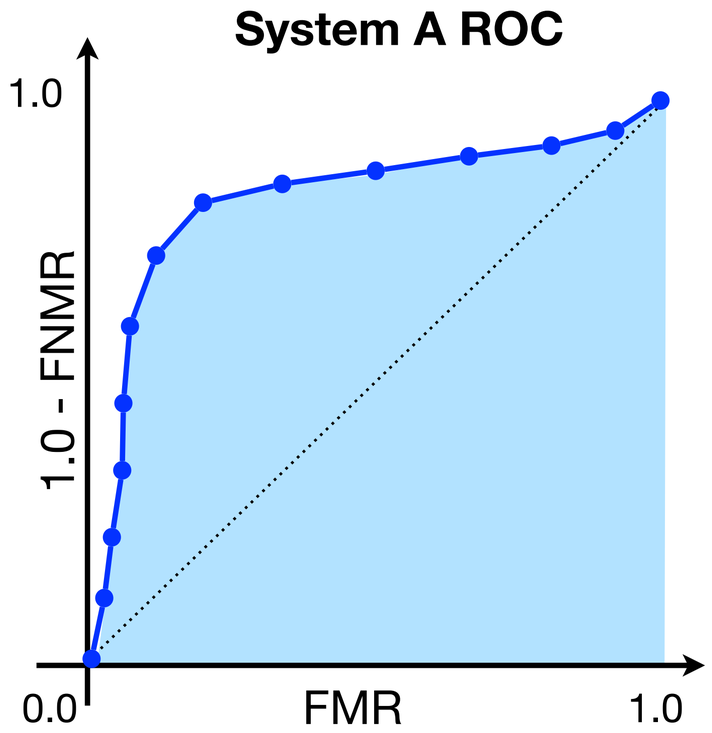


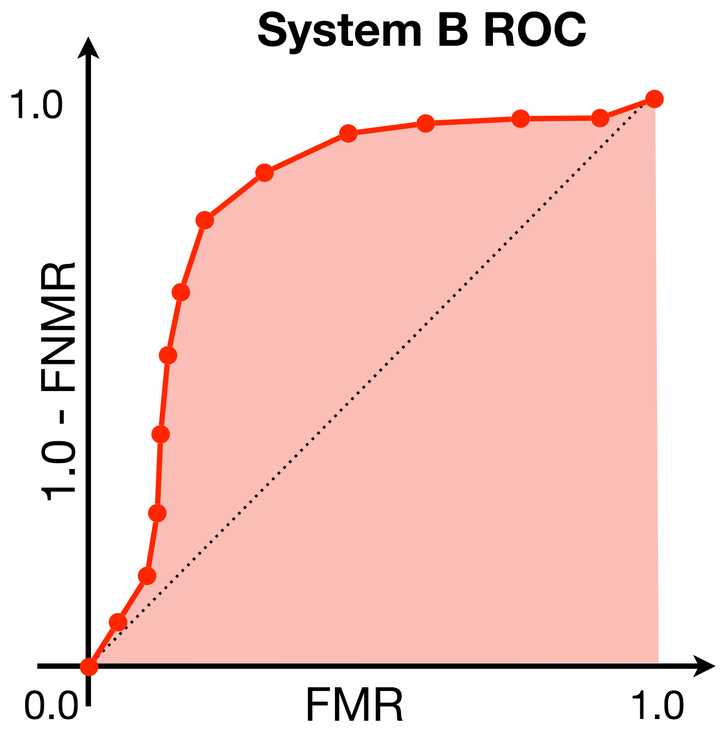




Metrics

How to compare two different systems?
Biometric systems *A* and *B.*



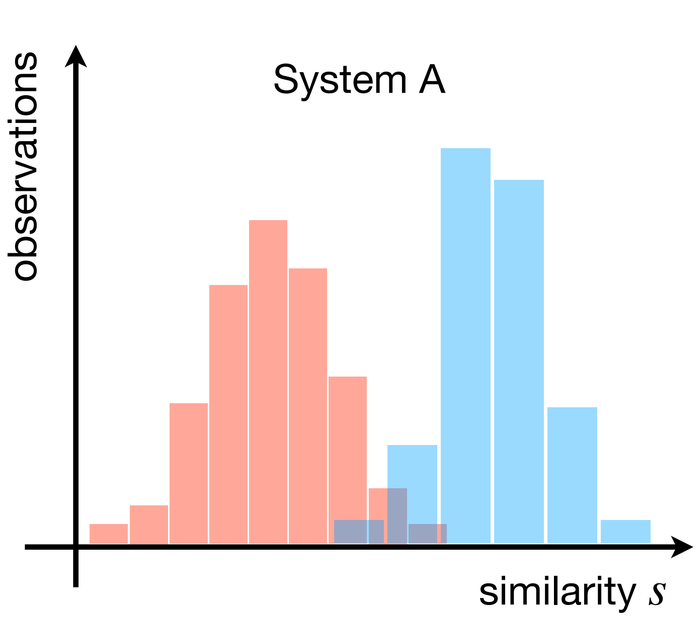


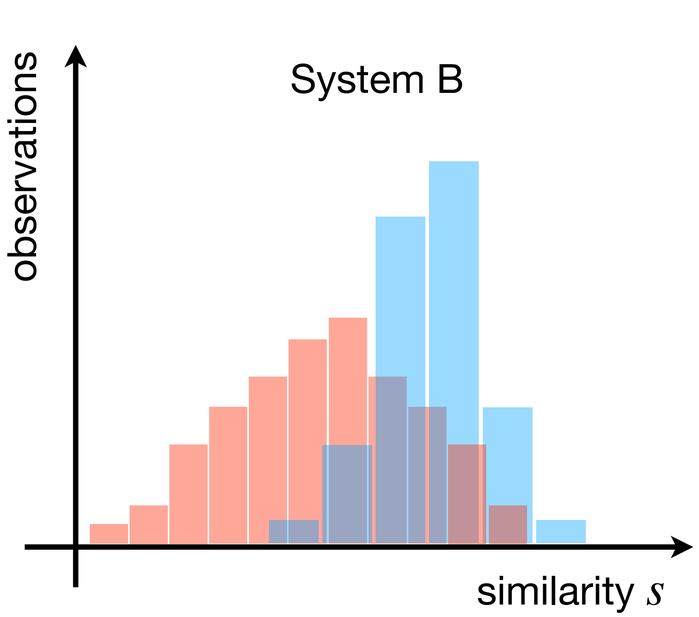
Which one is better?
Compute the
Area Under The Curve
(AUC).
The best solution
presents larger AUC.

Metrics

How to compare two different systems?
Biometric systems *A* and *B.*

Compute the difference between impostor and genuine distributions for each system (3/3)





impostor genuine

Which one is better?
Take the one with better separation of impostor and genuine observations.

It is System A!
How do we compute it?

Metrics

How to compare two different systems?
Biometric systems *A* and *B.*

Compute the difference between impostor and genuine distributions for each system (3/3)

Which one is better?
Take the system with
larger **d-prime**:

$$d' = \frac{\sqrt{2} \times |\mu_{genuine} - \mu_{impostor}|}{\sqrt{\sigma^2_{genuine} + \sigma^2_{impostor}}}$$

Hypothesis: the distributions are Gaussians (with mean μ and standard deviation σ).

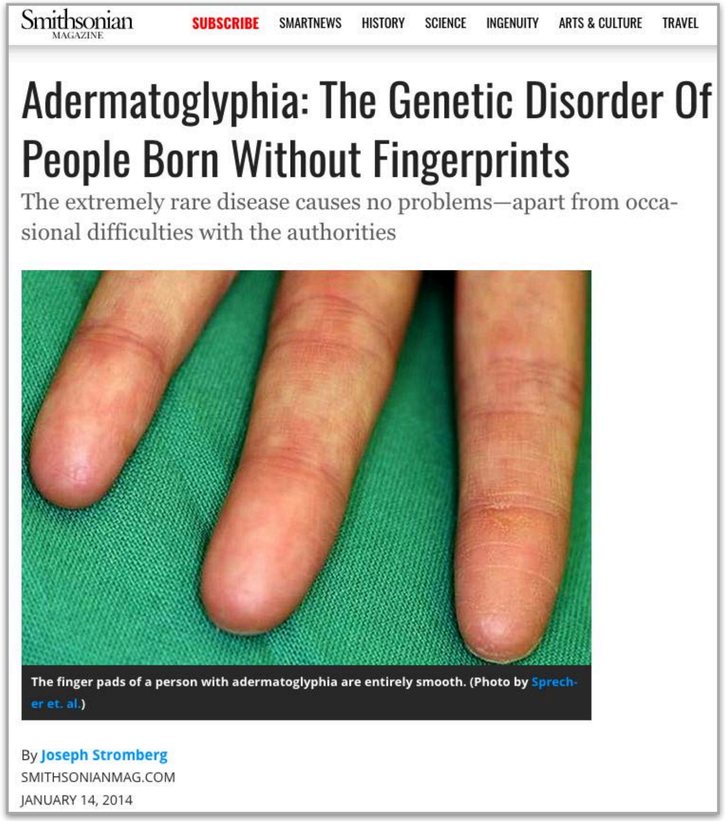
The larger the separation between the distributions, the larger the value of d-prime.

Metrics

Other Metrics (1/4, 2/4)

Failure to Acquire (FTA)
Rate of falsely rejected biometric samples due to problems in acquisition.

Failure to Enroll (FTE)
The same as FTA, but during enrollment.



https://www.smithsonianmag.com/science-nature/adermatoglyphia-genetic-disorder-people-born-without-fingerprints-180949338/

Metrics

Other Metrics (3/4, 4/4)

Positive Metrics
True Non-Match Rate (TNMR)
TNMR = 1.0 - FMR

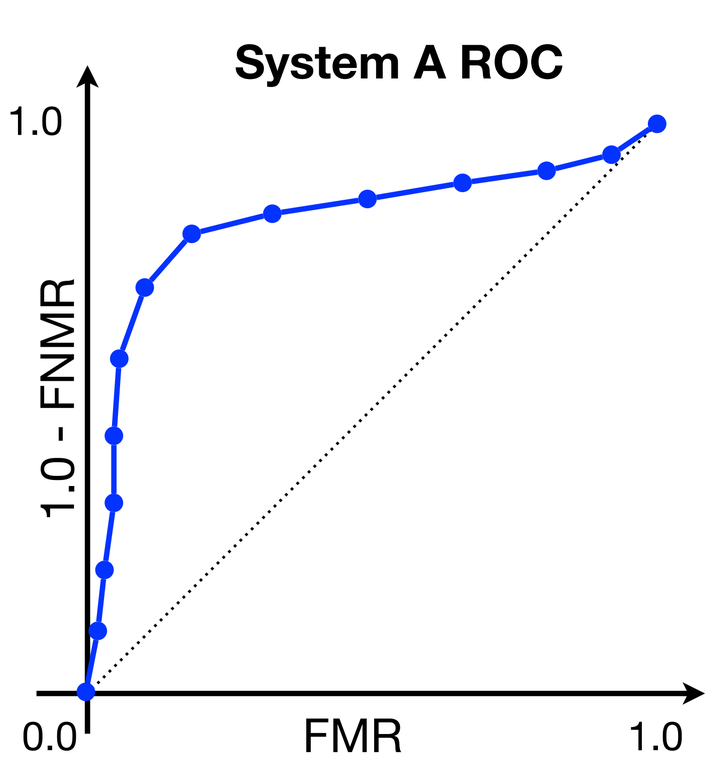
True Match Rate (TMR)
TMR = 1.0 - FNMR

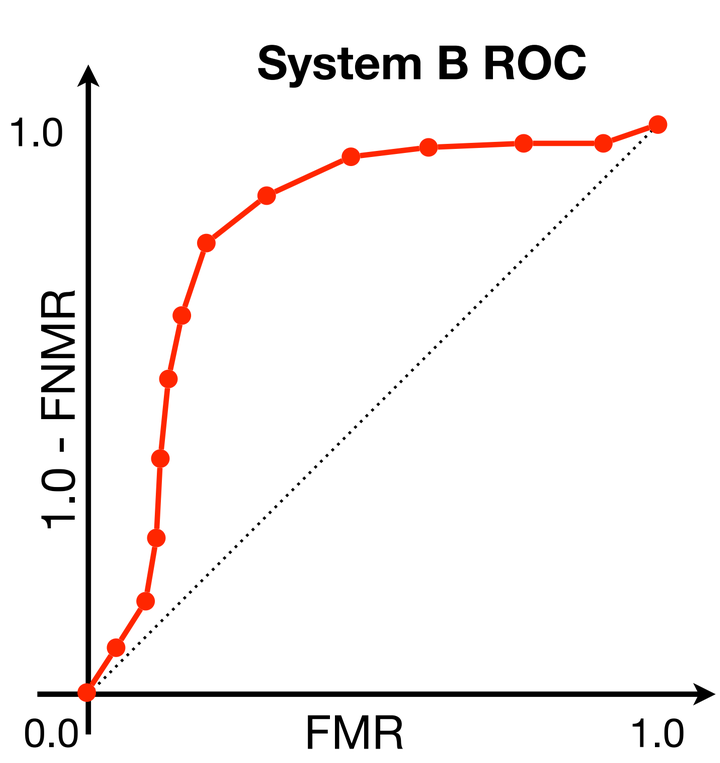
You want to maximize these instead of minimizing.

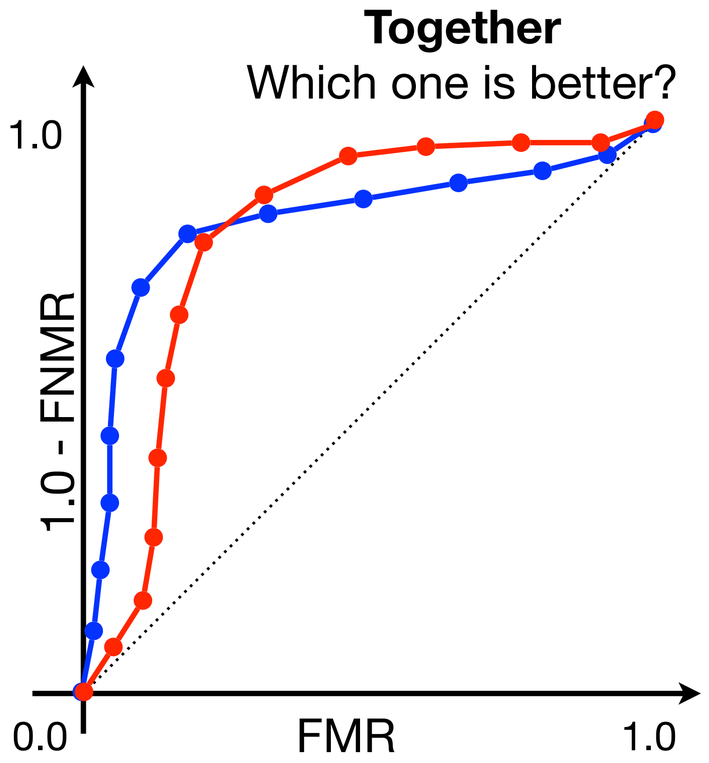
Metrics

How to compare two different systems?
Biometric systems *A* and *B.*

Compute FMR and FNMR for a variety of thresholds.







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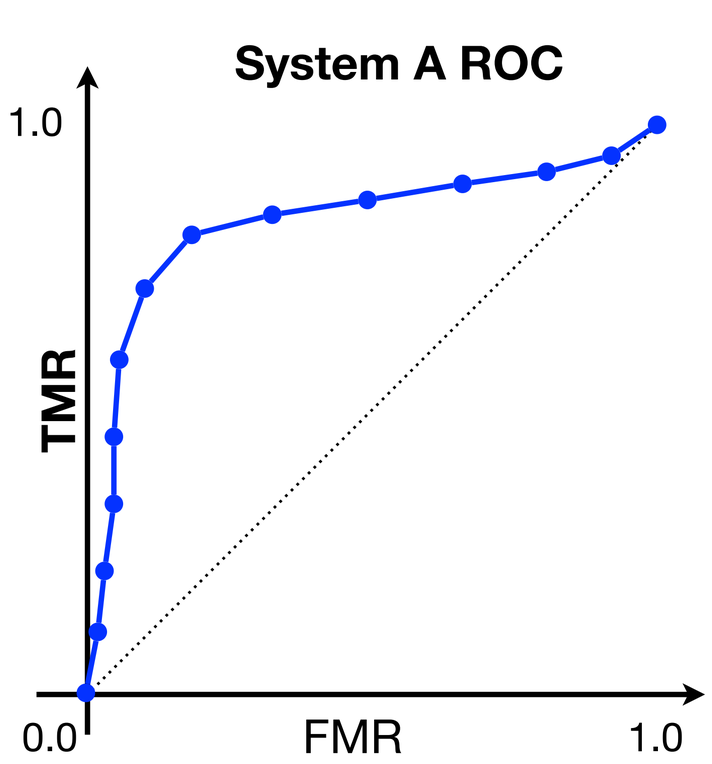

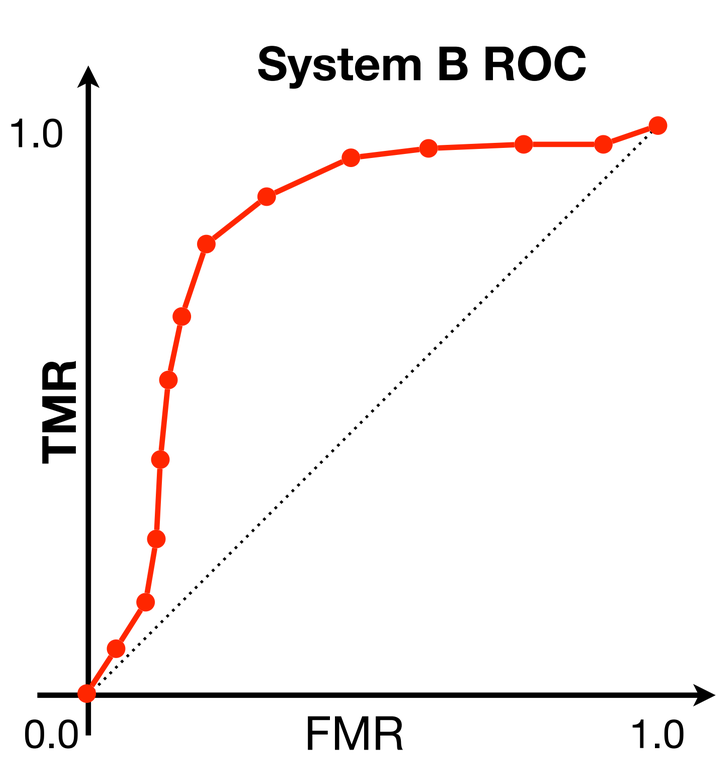

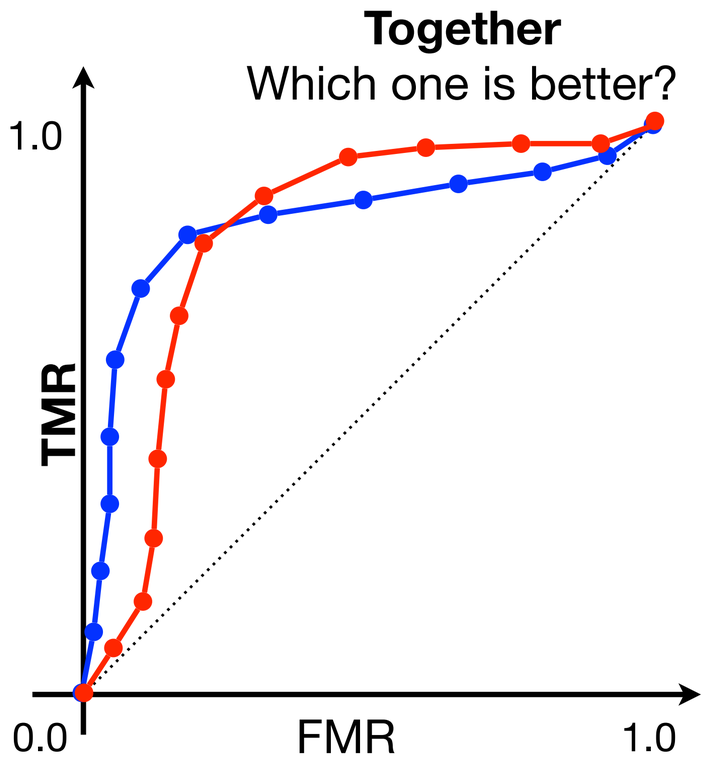

What's Next?

First Coding Day
Implementation of metrics.

Bring your computers
Don't have one?
Please let me know ASAP.

Be ready! :)
Tools: Google Colab.