Basics II

COMP 388-002/488-002 Biometrics

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Fall 2023

Today you will...

Discuss
Biometric systems and their errors.
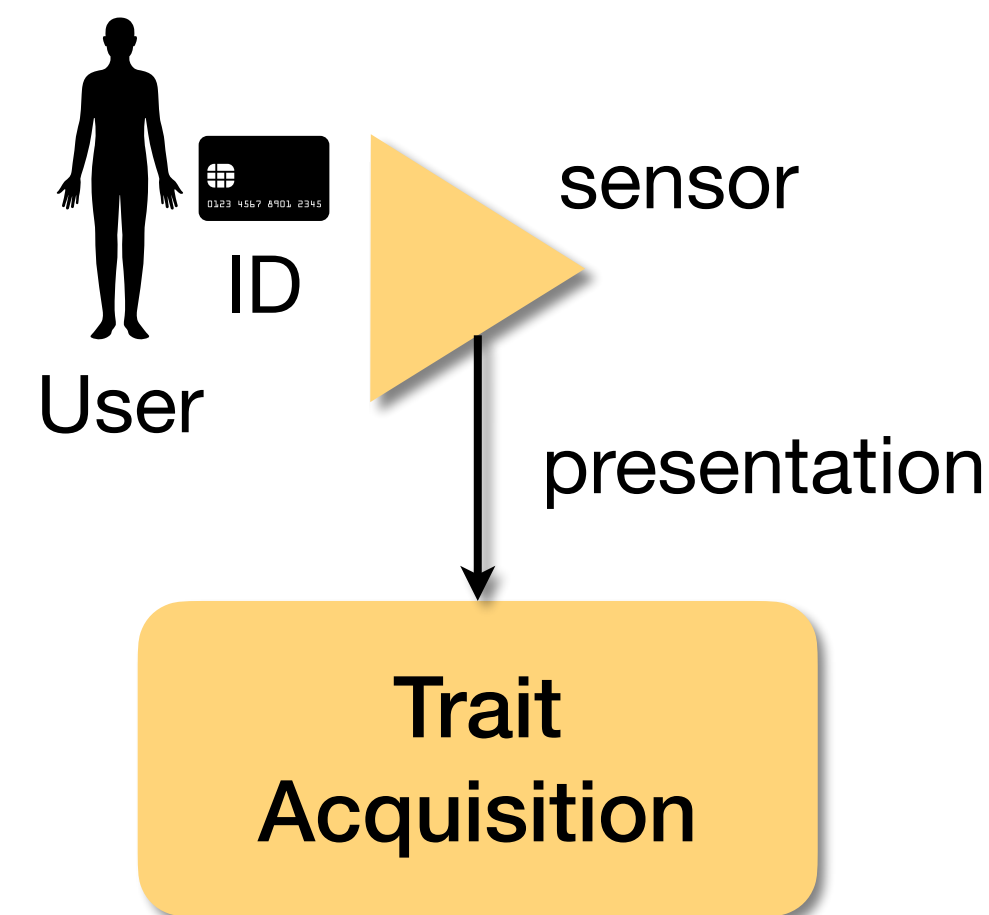Metrics to compare Biometric systems.

Today's attendance

Please fill out the form

https://forms.gle/11MHC4i3BMoL1aGs7

Biometric Systems

Enrollment

User — ID — sensor — presentation → Trait Acquisition
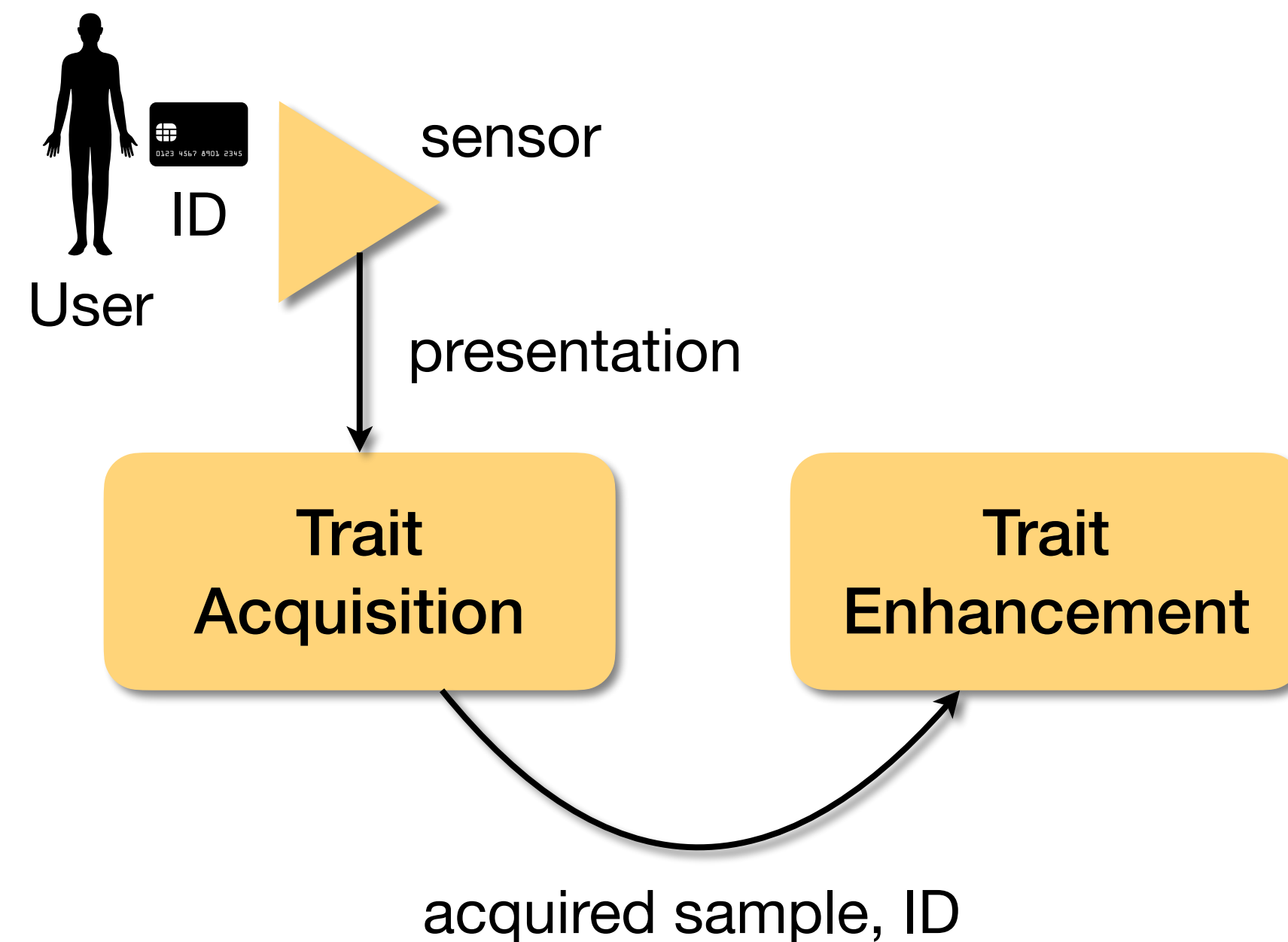
Trait Acquisition
We'll have data-collection classes.
We'll use real-world sensors.

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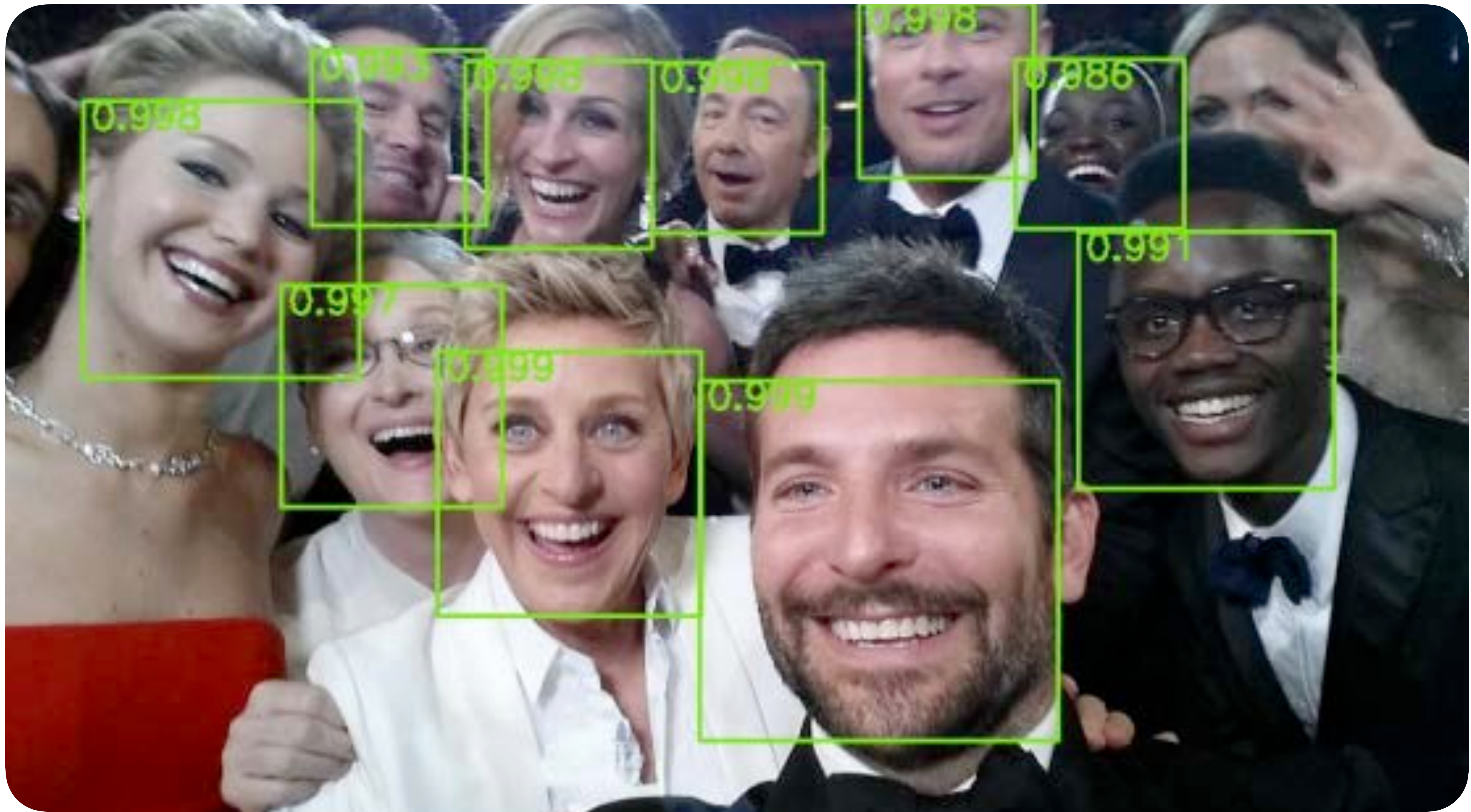
Biometric Systems

Enrollment

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

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   1x   1.0   3.0
1.0   1.0
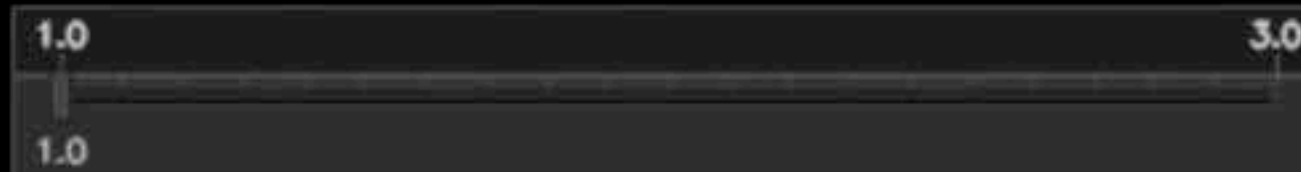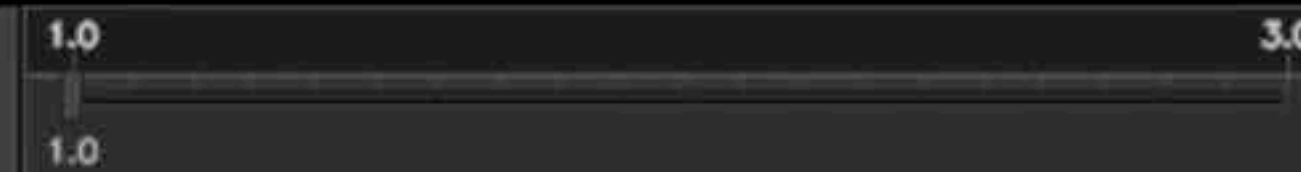
Human-Interpretable Features

■ TSHEPII   ☑ Show Matched   − 0 +   out of 0   ■ MSER   ☑ Show Matched   − 0 +   out of 0
            ☑ Show Unmatched   − 1 +   out of 0   ☑ Show Unmatched   − 1 +   out of 0

■ SURF   ☑ Show Matched   − 0 +   out of 0   ■ SIFT   ☑ Show Matched   − 0 +   out of 0
            ☑ Show Unmatched   − 1 +   out of 0   ☑ Show Unmatched   − 1 +   out of 0

■ Crypts   ☑ Show Matched   − 0 +   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

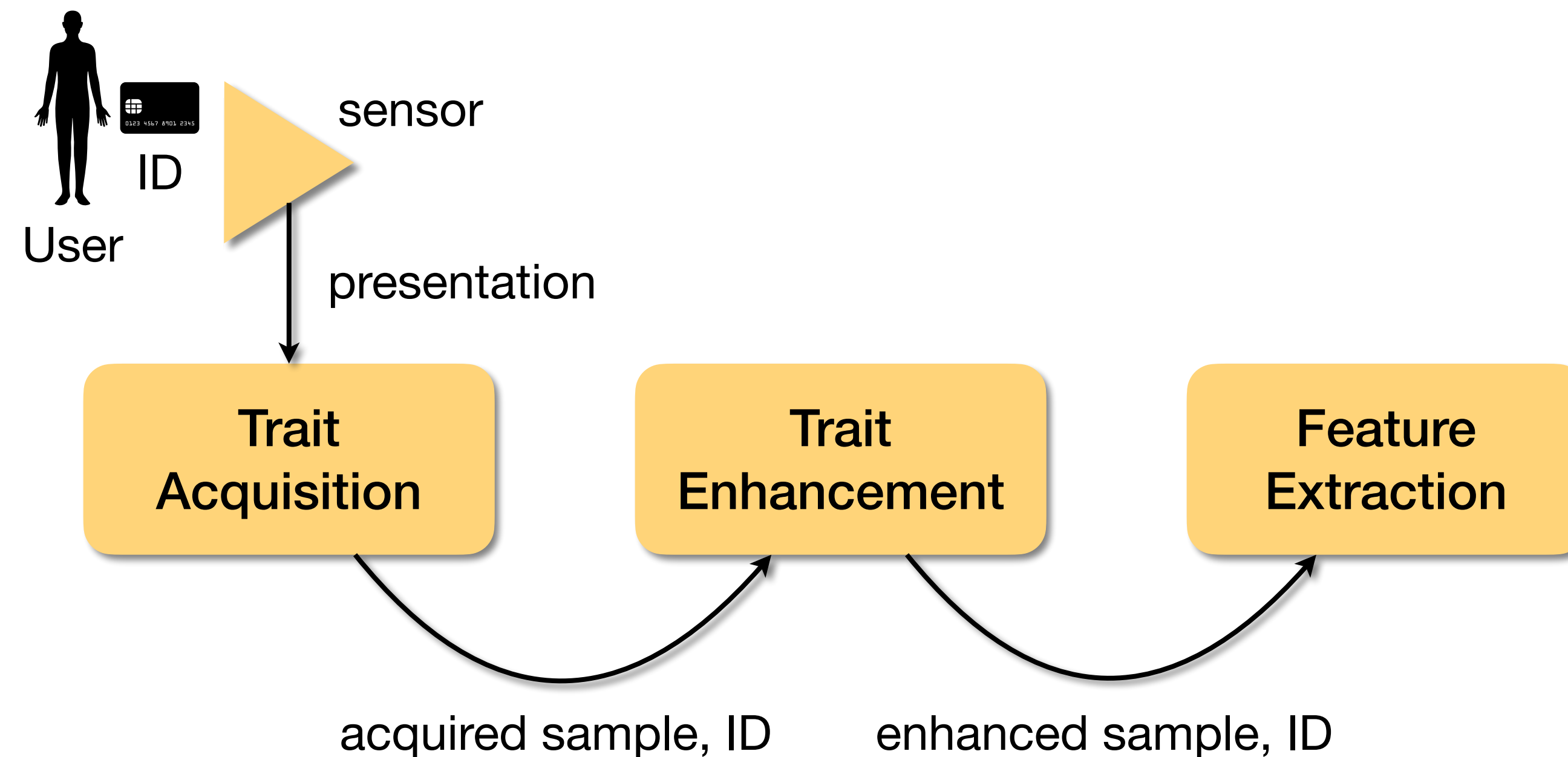Gabor Filters   BSIF Filters
        thr: 0.4461   thr: 0.4216

Global match score

Biometric Systems

Enrollment Modules

User
ID
sensor
presentation

Trait Acquisition → Trait Enhancement → Feature Extraction

acquired sample, ID   enhanced sample, ID

Feature Extraction
Compact but expressive digital representation of the trait.

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

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Biometric Systems

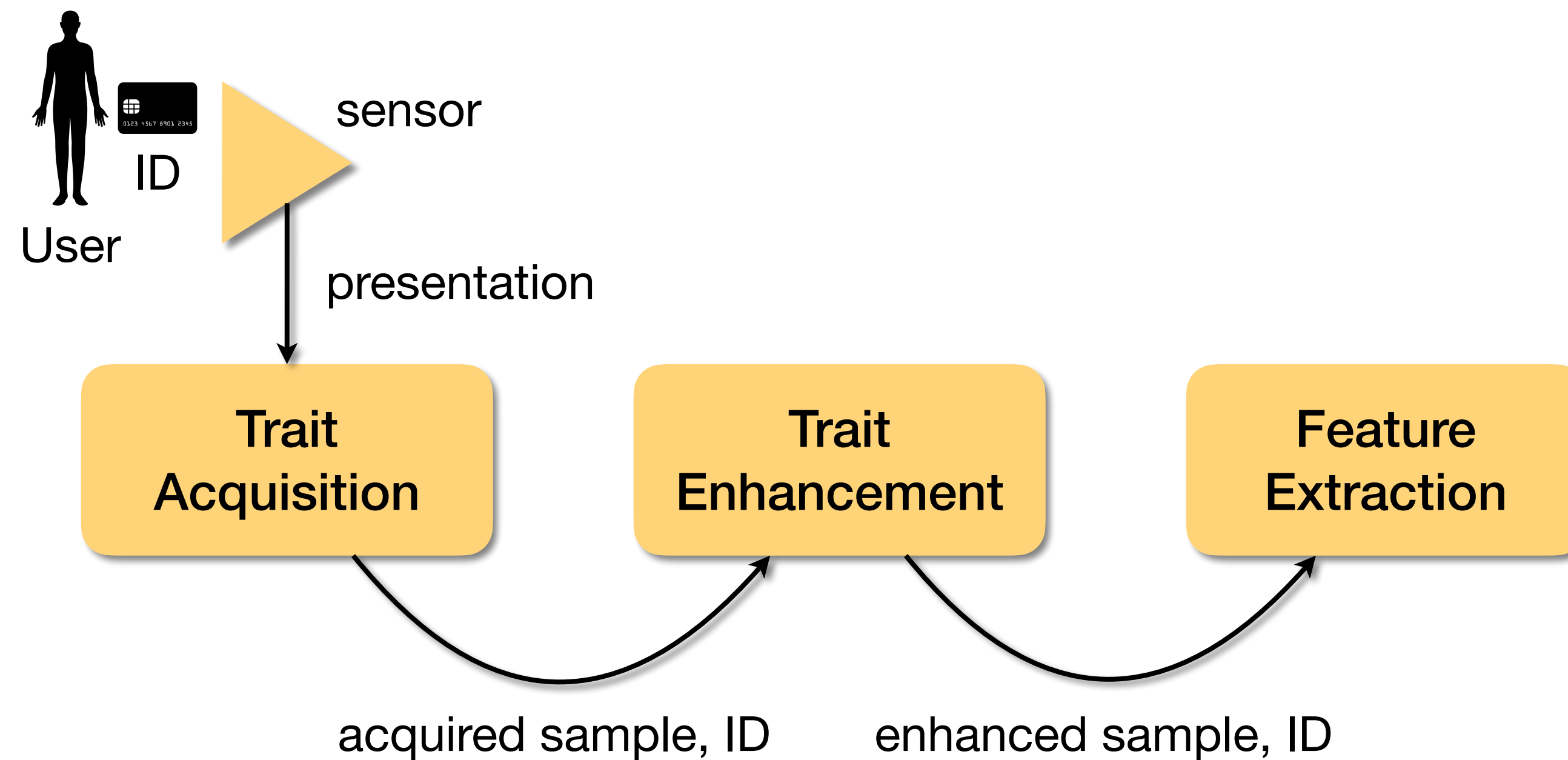**Enrollment Modules**
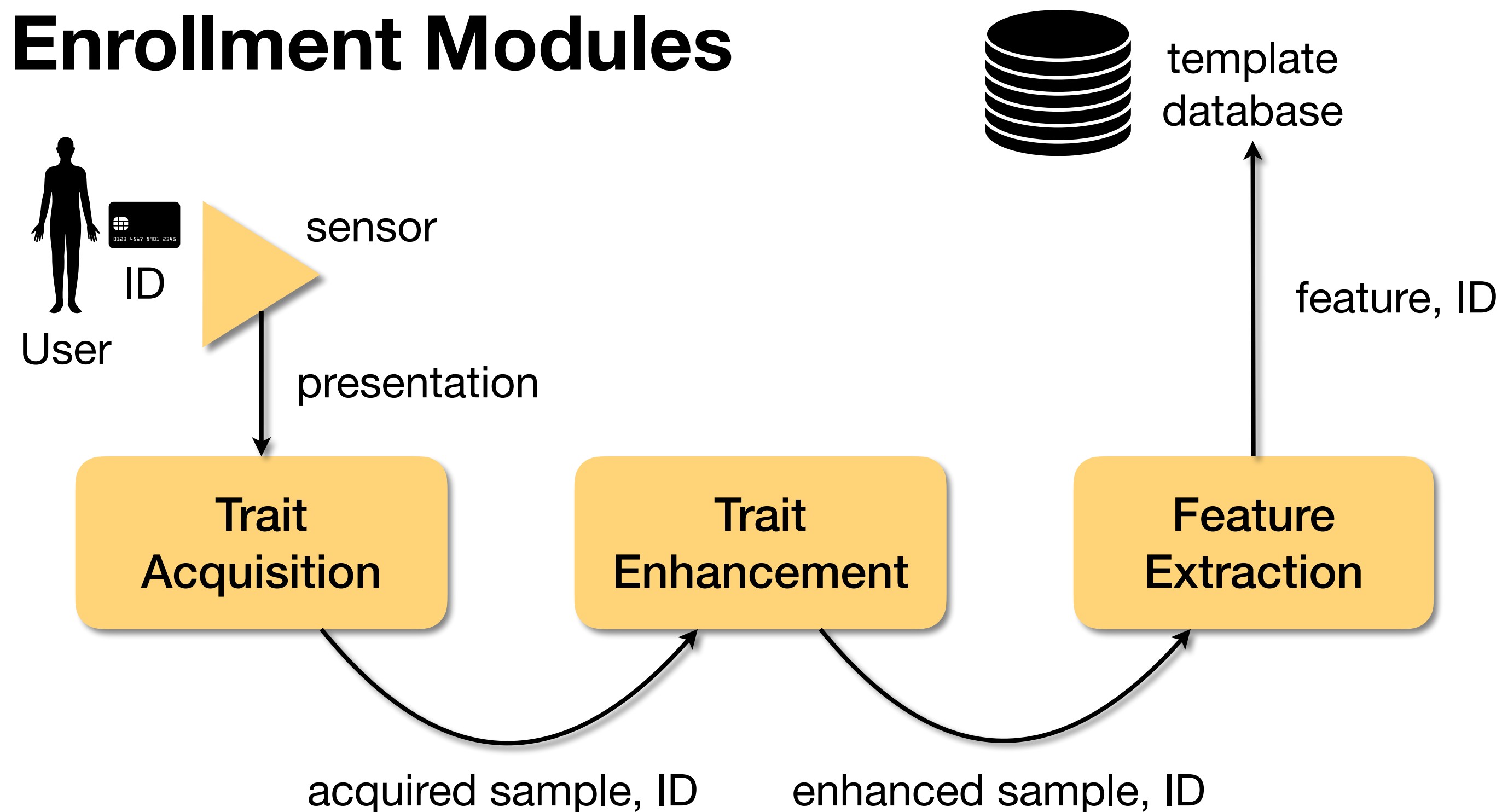
Template Database
It inherits all the security and privacy issues from database systems.
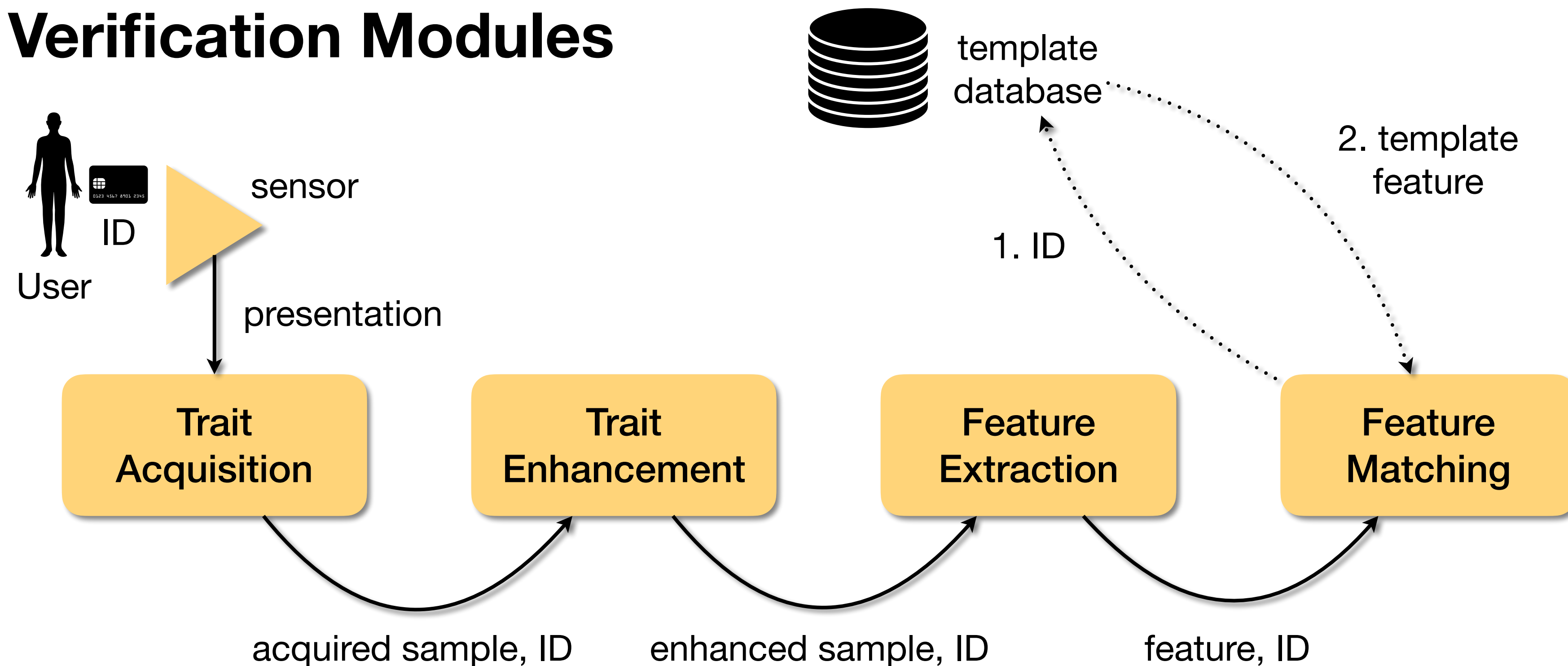Be careful with invasions, leaks, etc.

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Biometric Systems
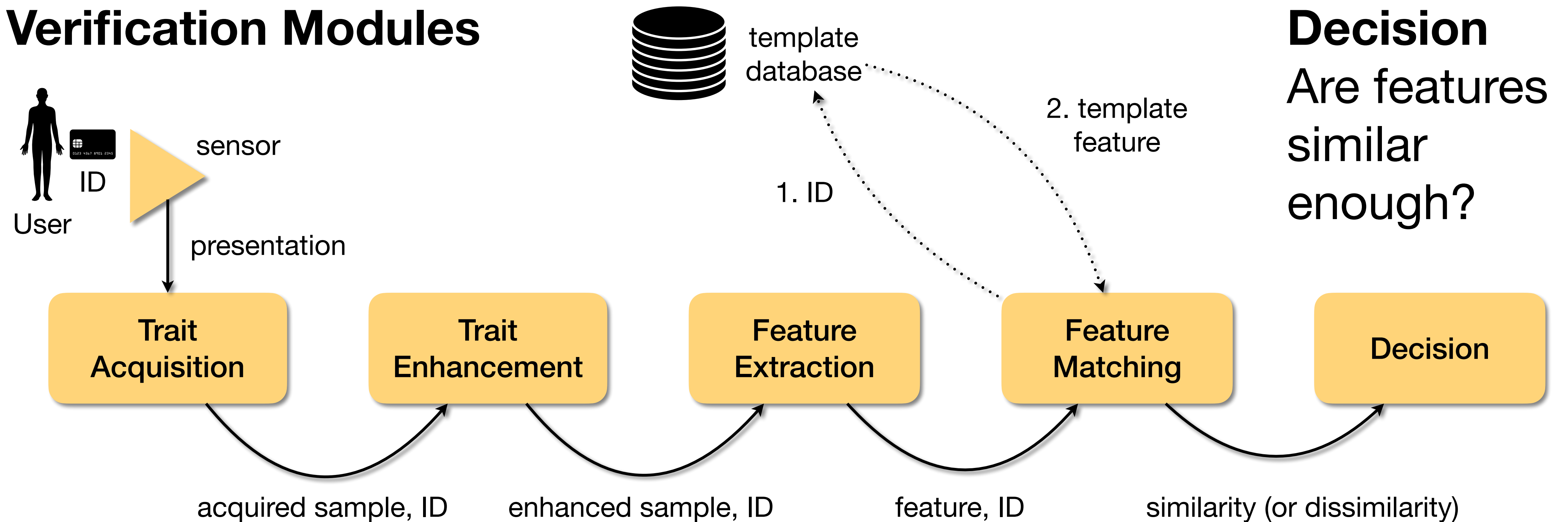
Verification Modules

Biometric Systems

Biometric Systems

Verification Modules

template database

Decision
Are features similar enough?

User
ID
sensor

presentation

2. template feature

1. ID

| Trait Acquisition | Trait Enhancement | Feature Extraction | Feature Matching | Decision |

acquired sample, ID   enhanced sample, ID   feature, ID   similarity (or dissimilarity)

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Biometric Systems

Verification Modules

Biometric Systems

Identification Modules

User — sensor — presentation

template database
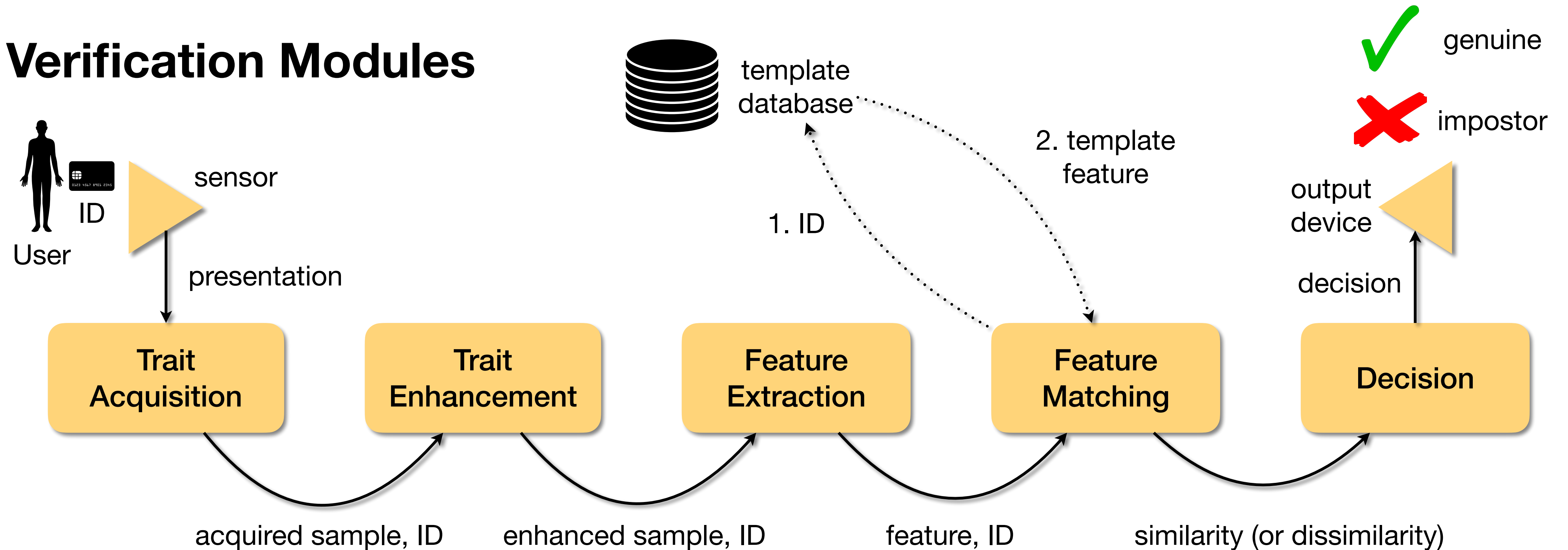
1. feature **query**

2. feature **gallery** (with IDs)
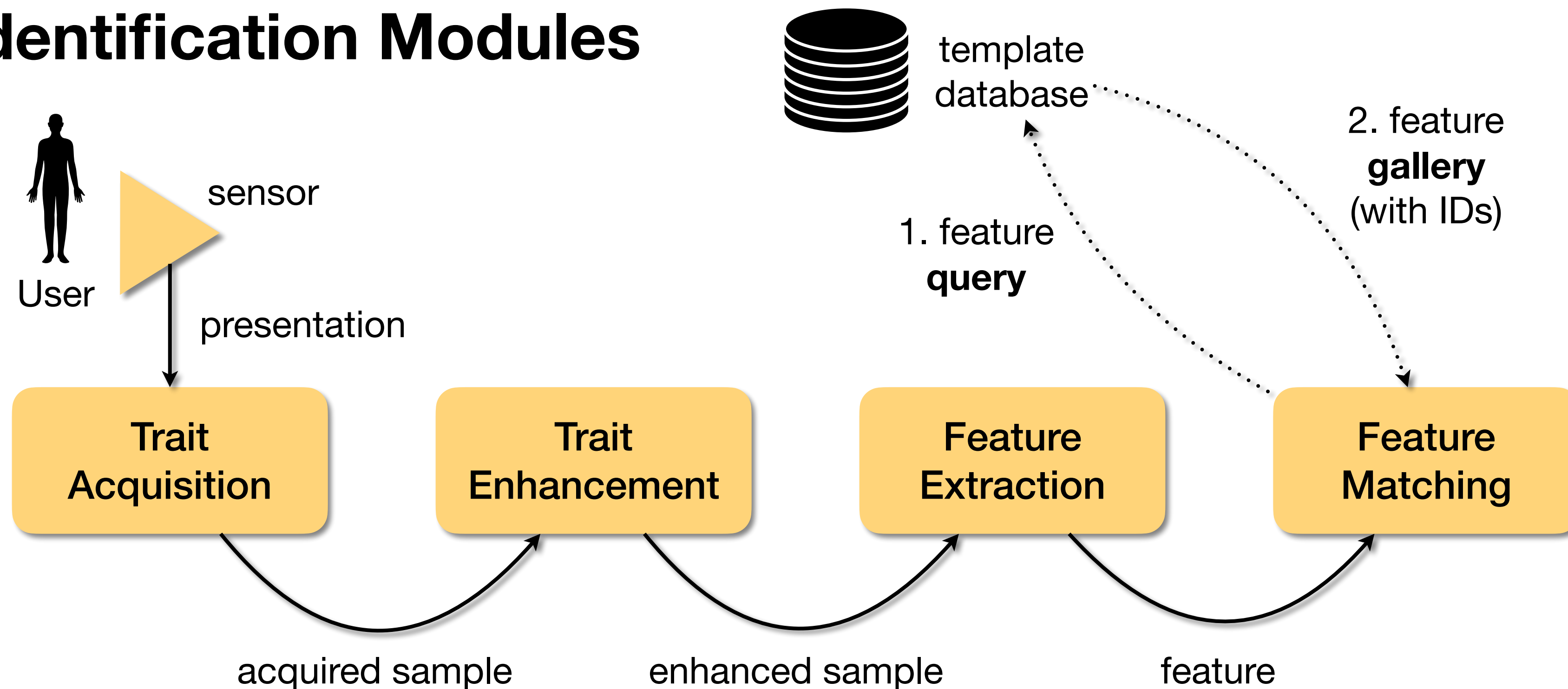
Gallery
Closest template features to query.

Trait Acquisition → *acquired sample* → Trait Enhancement → *enhanced sample* → Feature Extraction → *feature* → Feature Matching

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Biometric Systems

Query and Gallery Example

query

gallery

Biometric Systems

Identification Modules

template database

Decision
Open-set identification is necessary.

User

sensor

presentation

1. feature **query**

2. feature **gallery** (with IDs)

| Trait Acquisition | Trait Enhancement | Feature Extraction | Feature Matching | Decision |

acquired sample   enhanced sample   feature   query, gallery (with IDs), and similarities

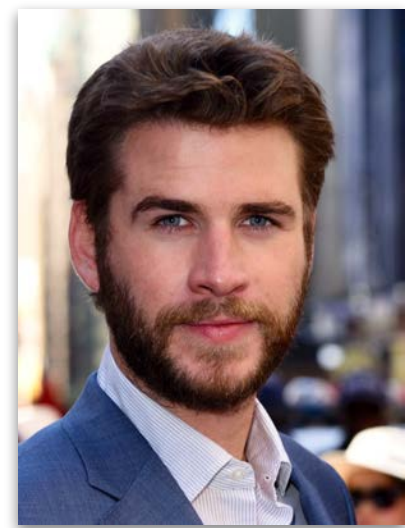LOYOLA UNIVERSITY CHICAGO
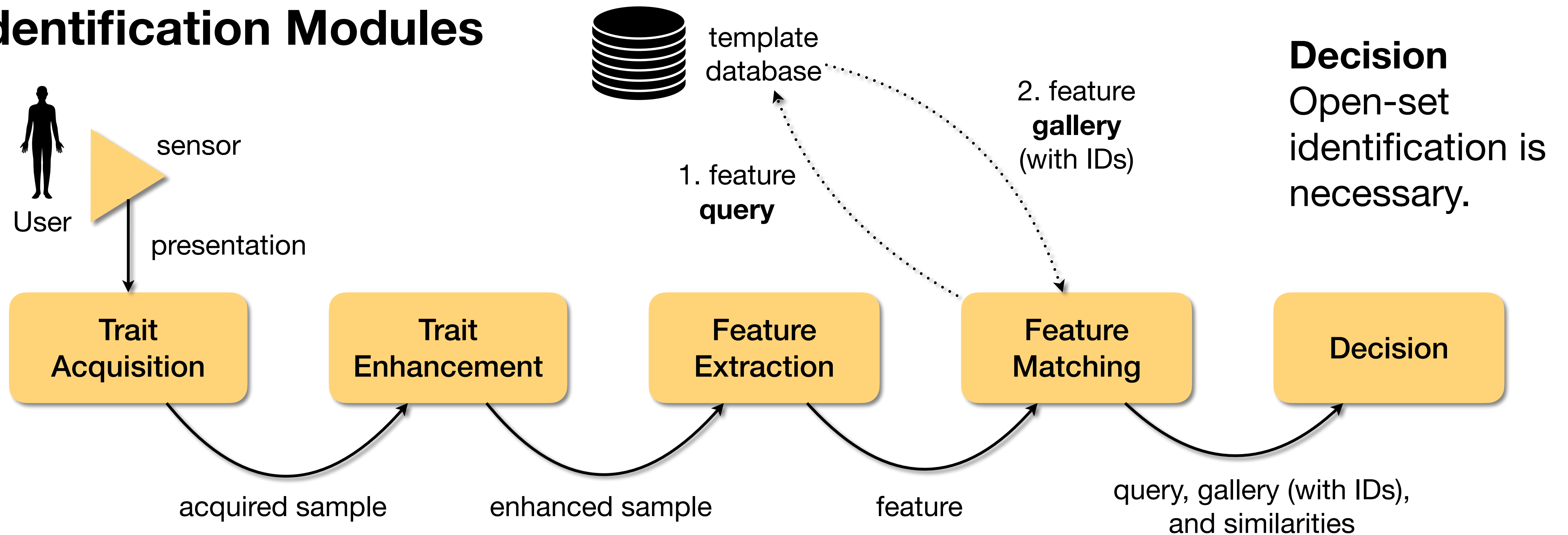
Biometric Systems

Open-set vs. Closed-set Identification

Query
(Liam Hemsworth)

Dataset

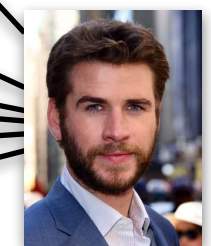Robert Downey Jr.

Scarlet Johansson

Chris Evans

Mark Ruffalo

Chris Hemsworth

Jeremy Renner

Feature Space

Closed Set

Output
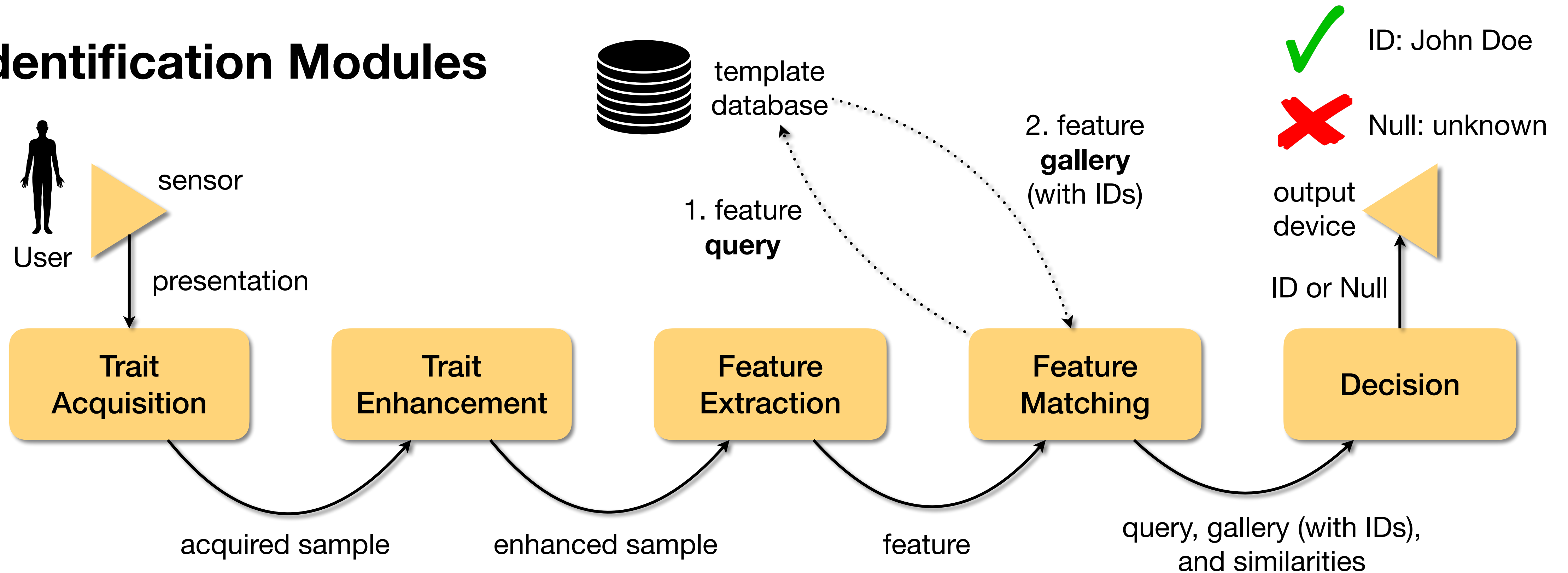This is Chris Hemsworth!

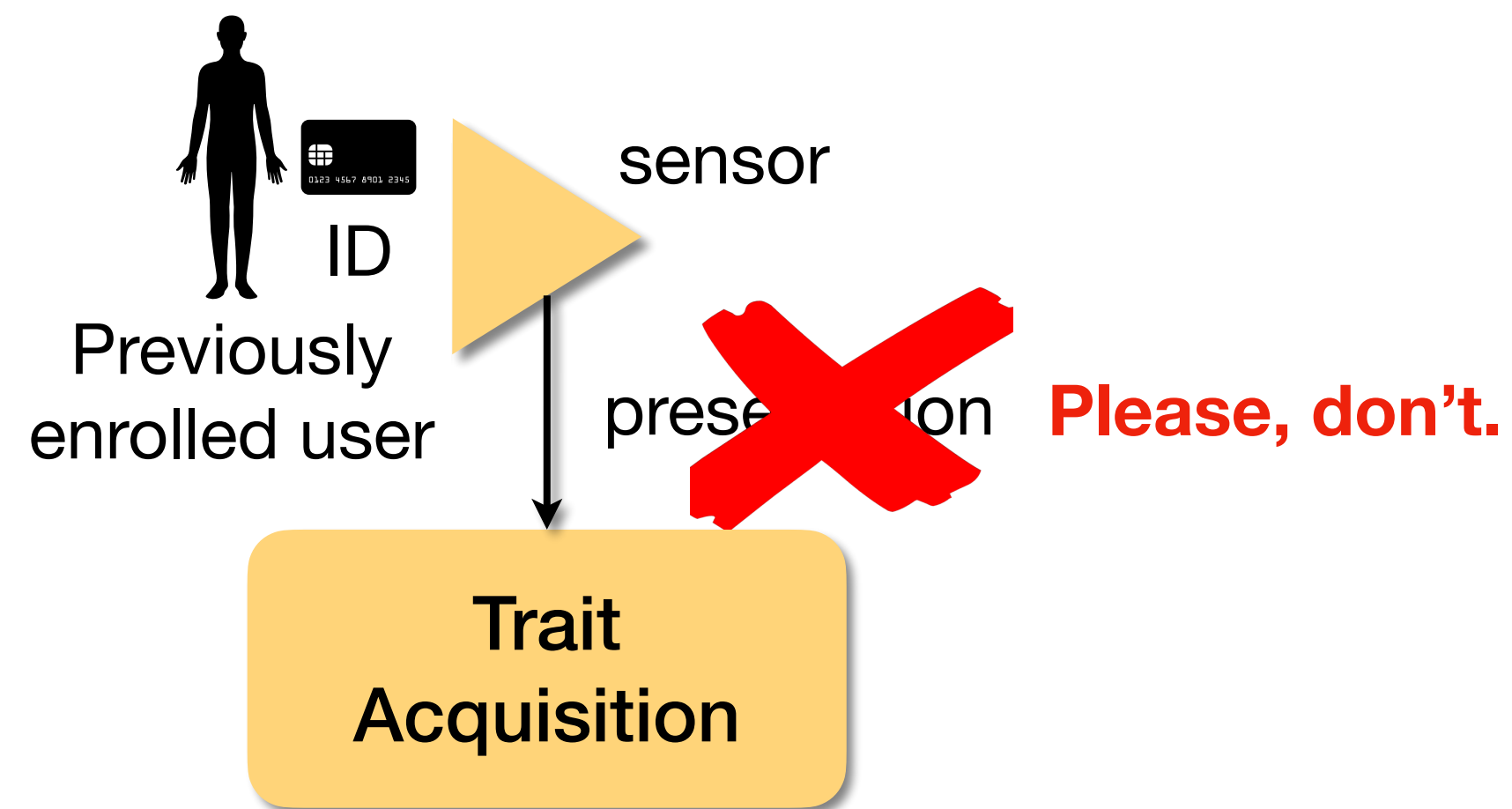### Open Set

Output
I don't know this person!

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Biometric Systems

Biometric Systems

Enrollment Revision

ID

Previously enrolled user
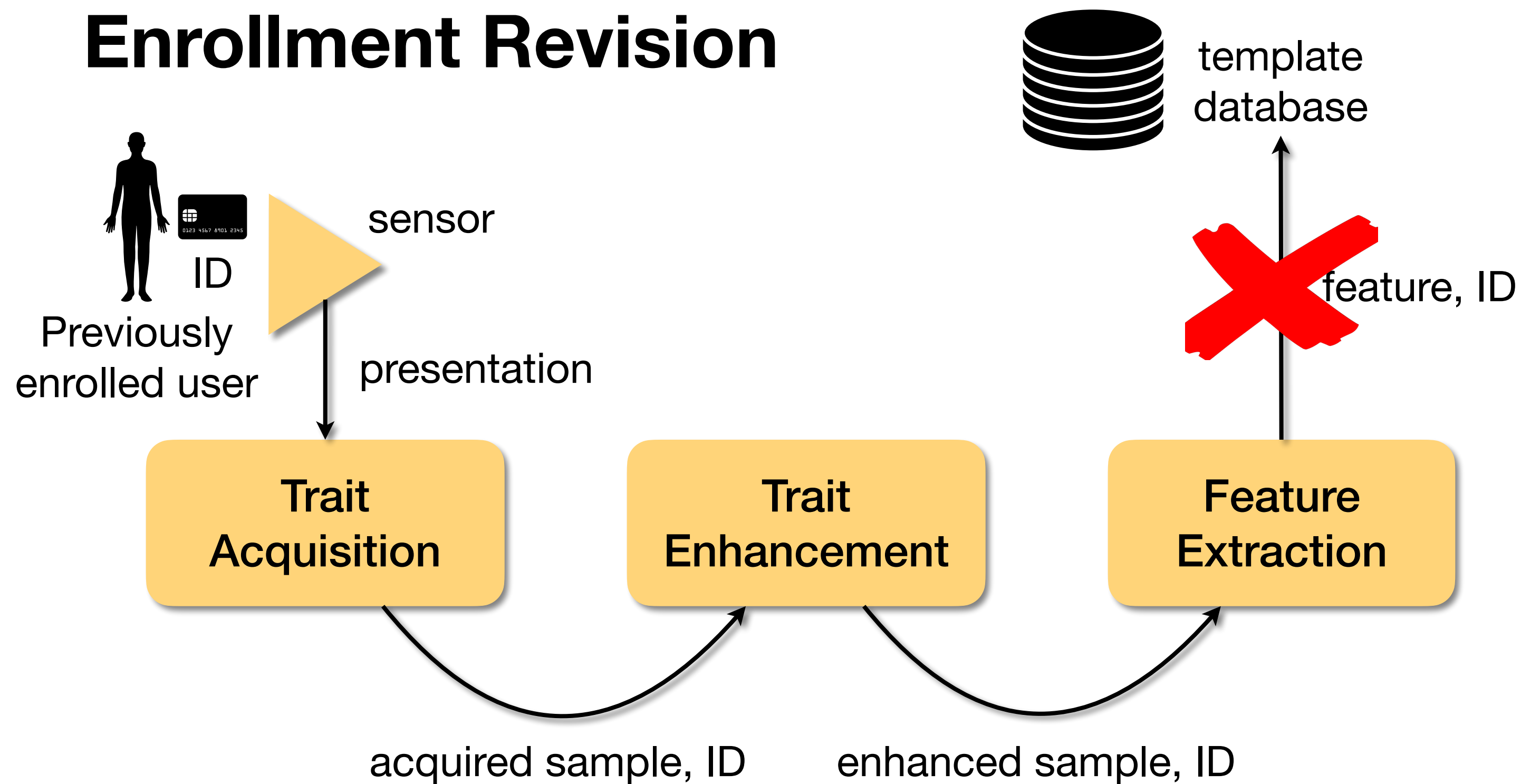
sensor

presentation **Please, don't.**

Trait Acquisition

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

Biometric Systems

Enrollment Revision

template
database

sensor

ID
Previously
enrolled user

presentation

**Trait
Acquisition**

**Trait
Enhancement**

**Feature
Extraction**

acquired sample, ID

enhanced sample, ID

feature, ID

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

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Biometric Systems

Enrollment Revision

template database

✓ Null: Enrolled!

✗ ID: Already-enrolled error.

ID
Previously enrolled user

sensor

presentation

1. feature **query**

2. feature **gallery** (with IDs)

ID or Null

Trait Acquisition	Trait Enhancement	Feature Extraction	Feature Matching	Decision

acquired sample, ID

enhanced sample, ID

feature

query, gallery (with IDs), and similarities

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Biometric Systems

Enrollment Revision

ID
Previously enrolled user

sensor

presentation

template database

1. feature **query**

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.

Trait Acquisition	Trait Enhancement	Feature Extraction	Feature Matching	Decision

acquired sample, ID   enhanced sample, ID   featu

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Biometric Systems

Enrollment Revision

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

sensor

ID
Previously enrolled user

presentation

template database

feature, ID

Trait Acquisition	Trait Enhancement	Feature Extraction	Feature Matching	Decision

acquired sample, ID

enhanced sample, ID

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

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Biometric Systems

Enrollment Revision

sensor

ID
Previously enrolled user

presentation

Trait Acquisition

Trait Enhancement

acquired sample, ID   enhanc

template database

De-duplication
Once the system has finally found a duplication, remove it, and take other necessary actions.

ID: Already-enrolled error. Remove duplication.

Feature Matching

Decision

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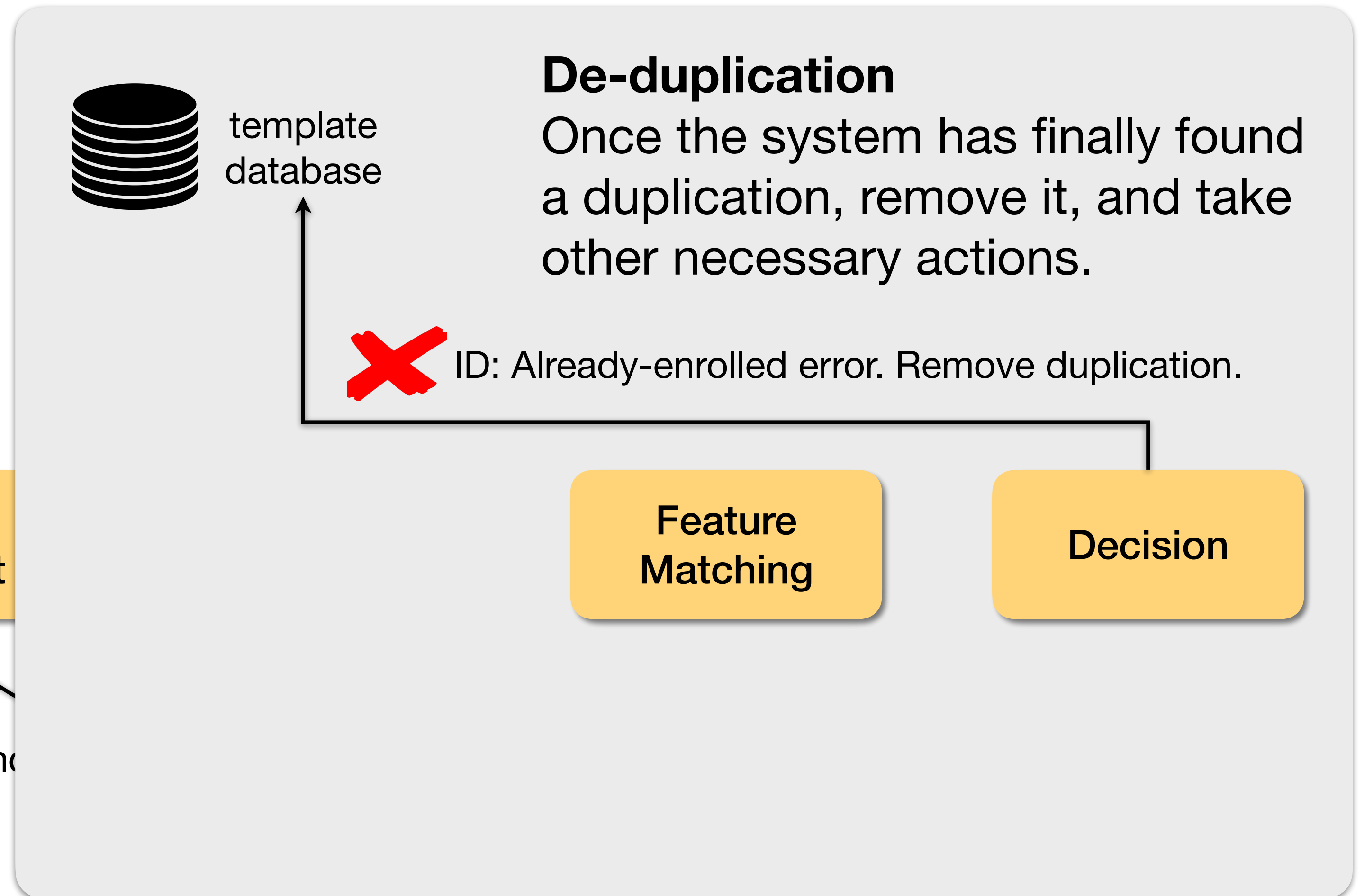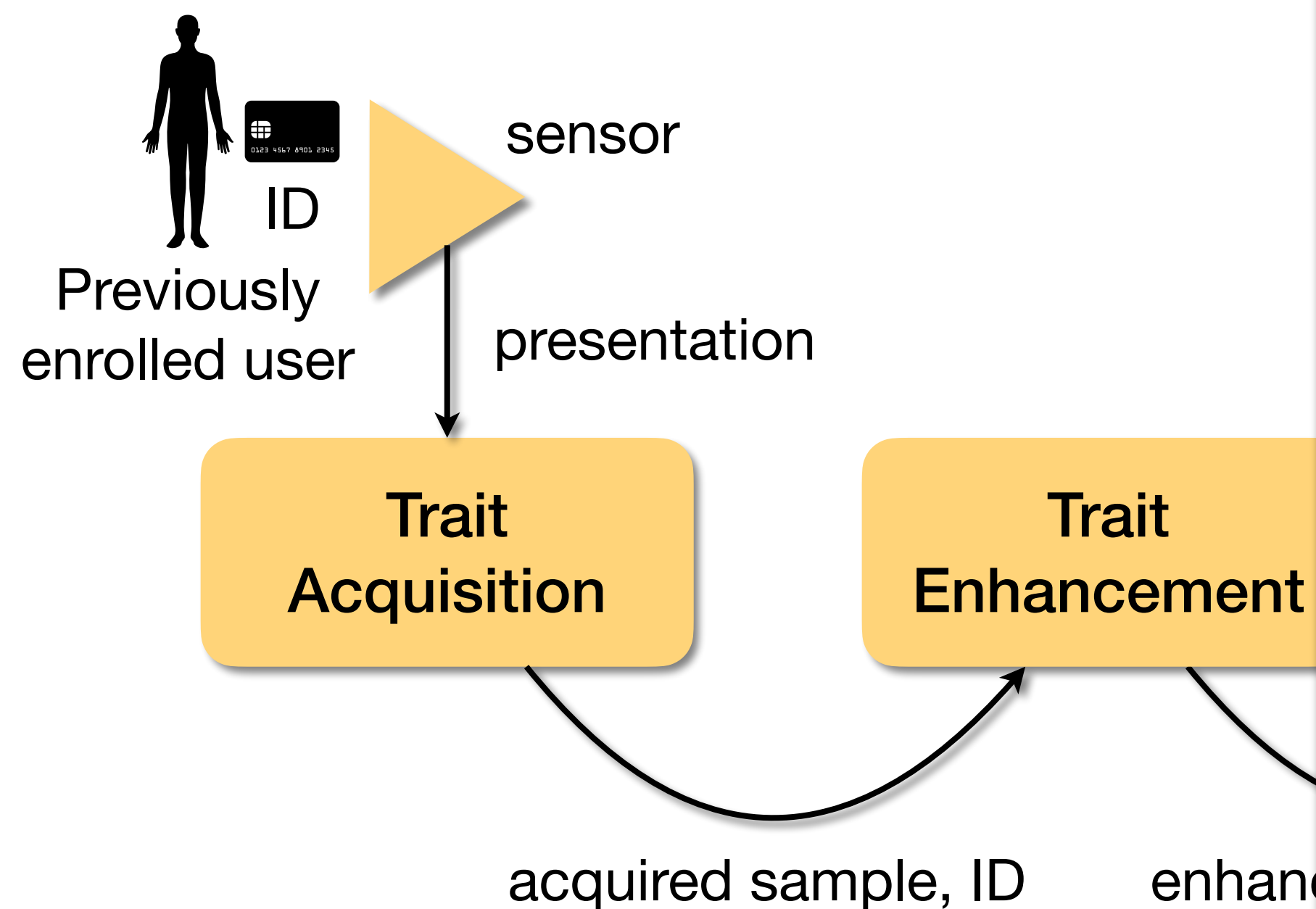
Biometric Systems

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)**
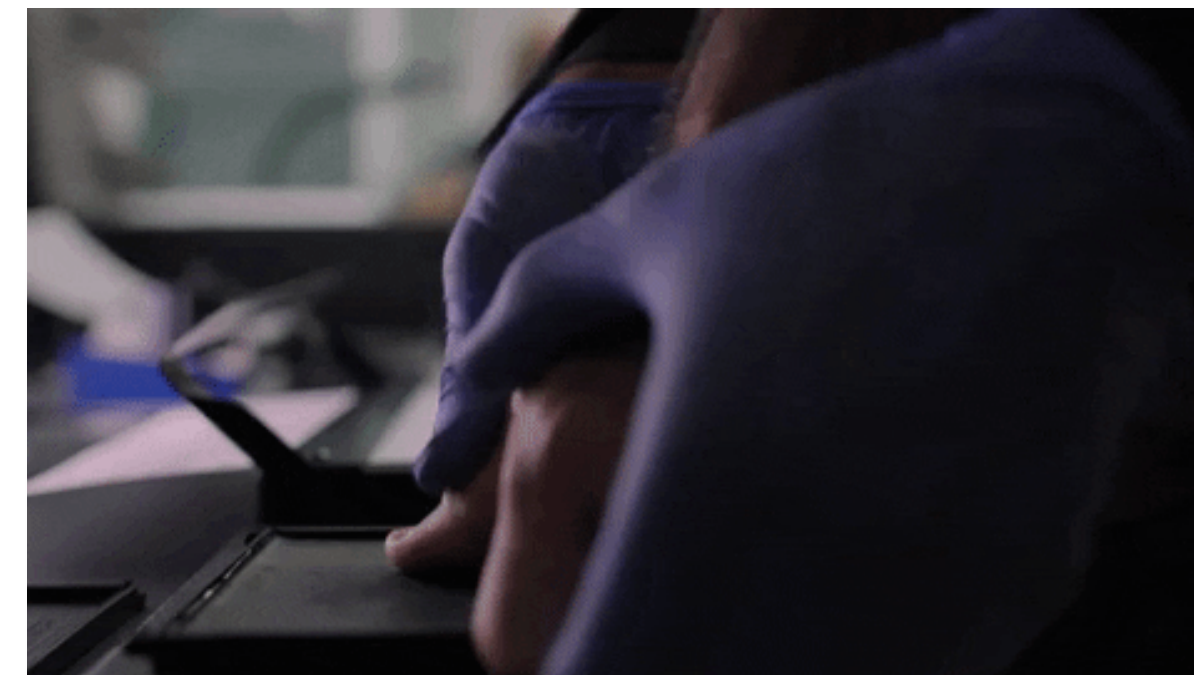Do users interact with the system frequently or sporadically?

TO START
PRESS ANY KEY

"TO START, PRESS ANY KEY."
WHERE'S THE "ANY" KEY?

Biometric Systems

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

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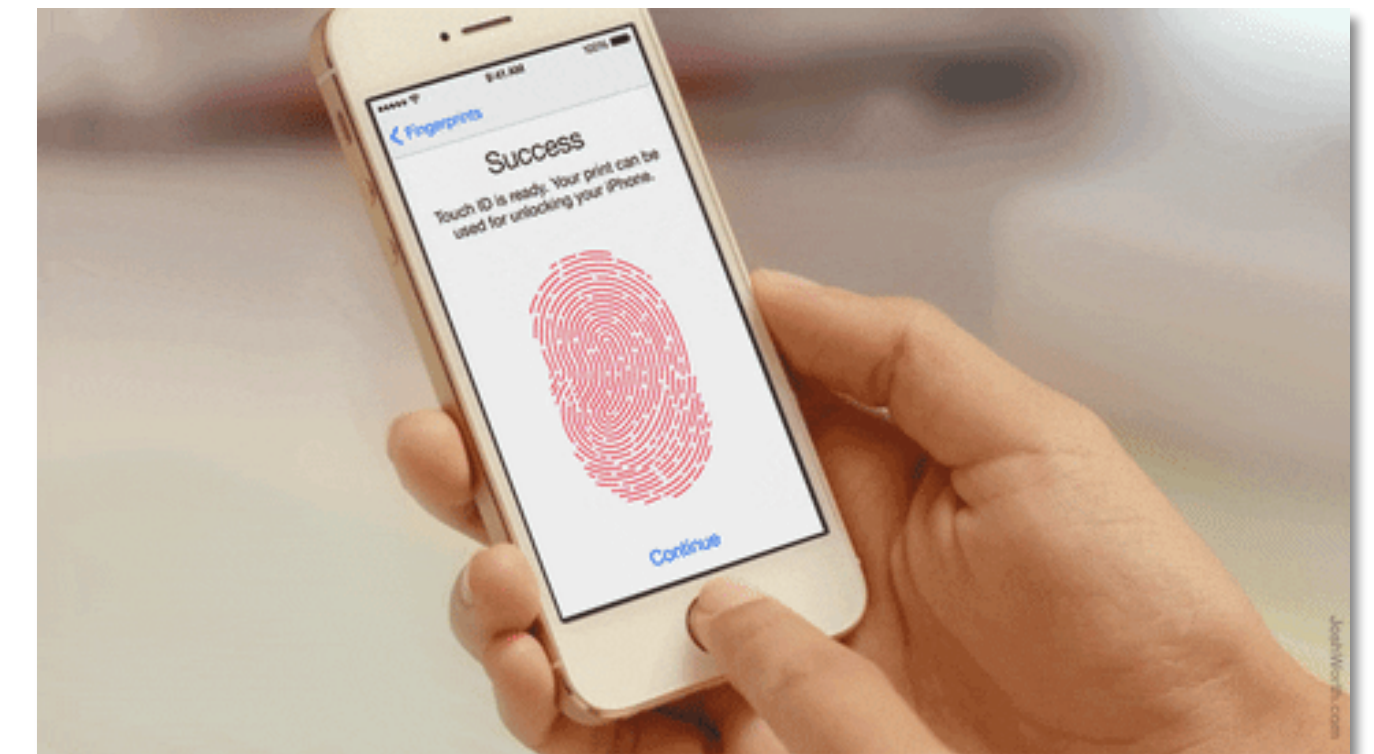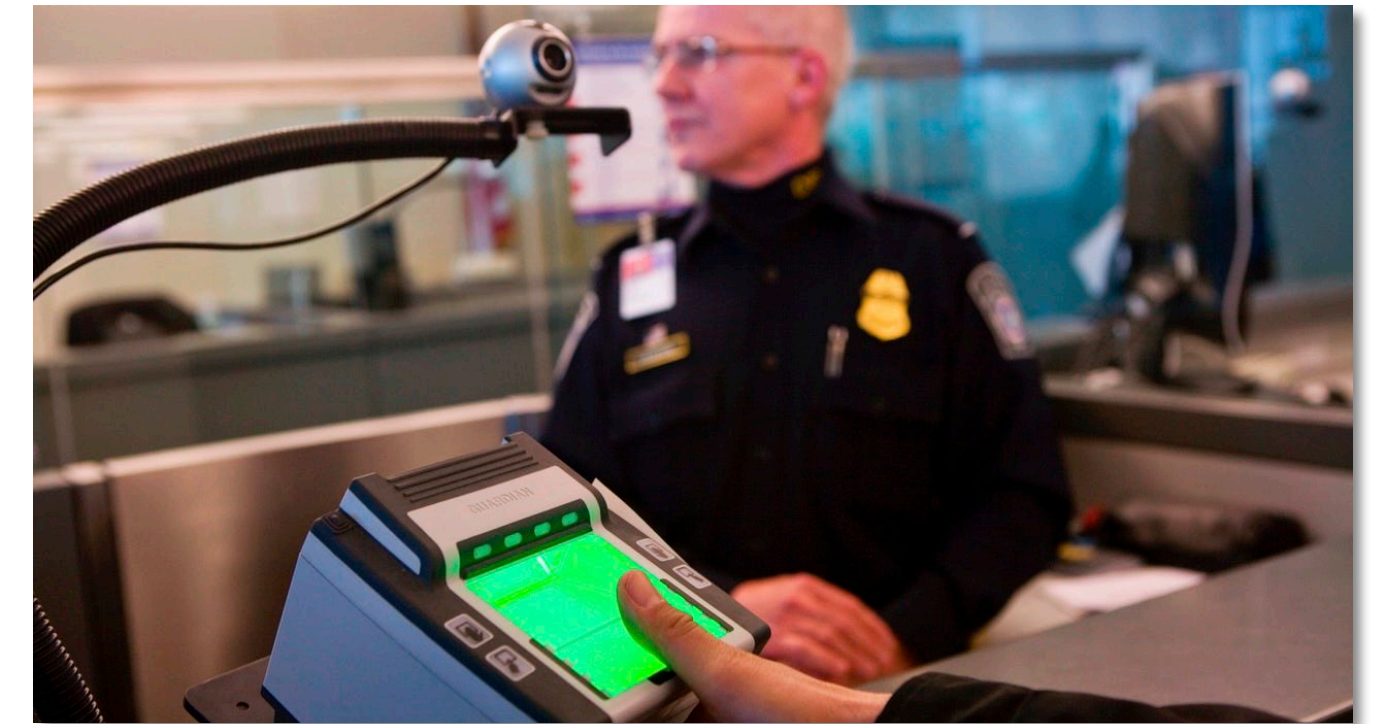Will somebody be
helping users?

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.

THIS IS SO SLOW

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.

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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/

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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.

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Biometric System Errors

Repudiation (3/3)

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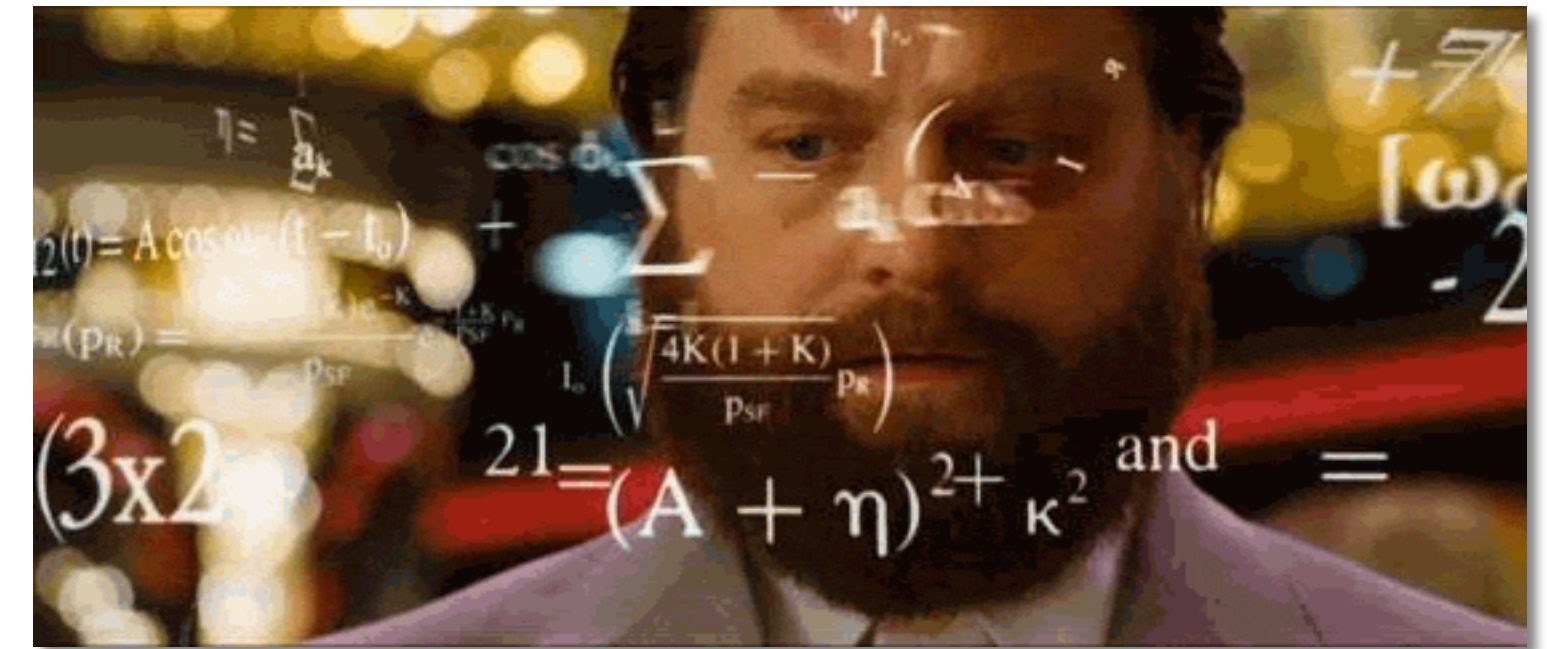
Adversarial attack: obfuscation.

obfuscation

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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.
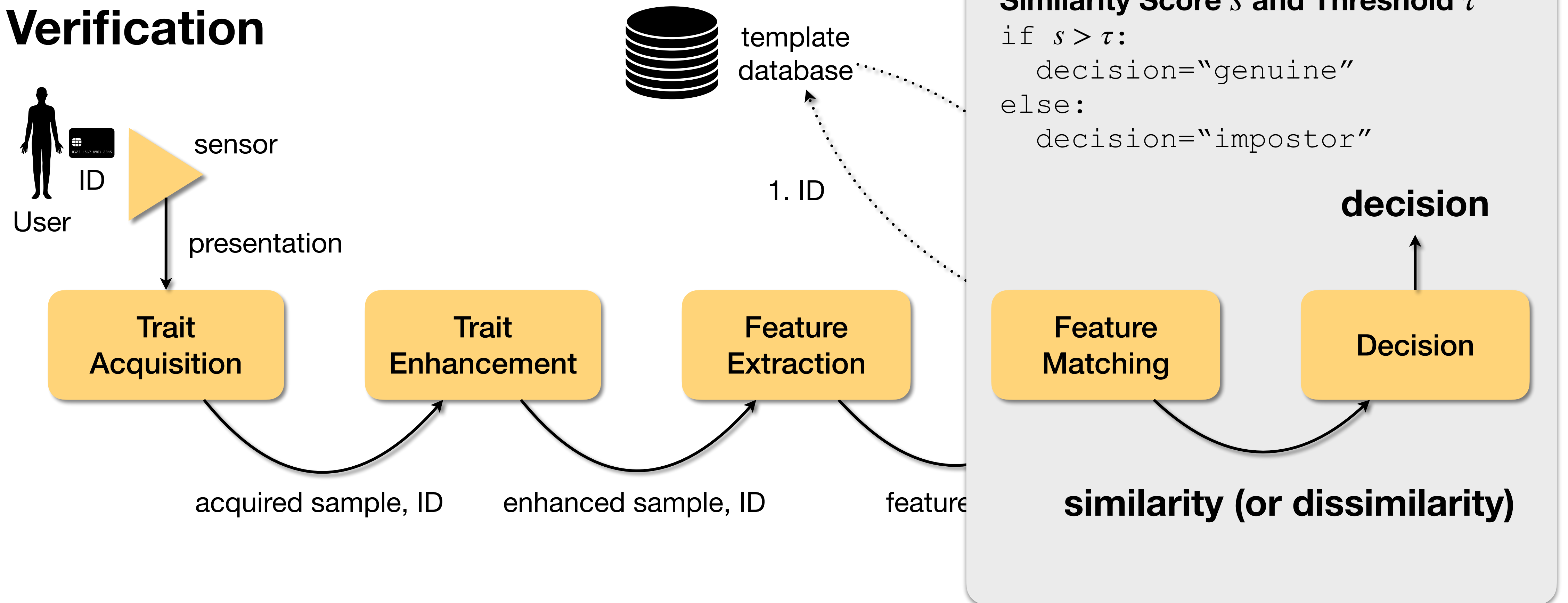It helps an intrusion.

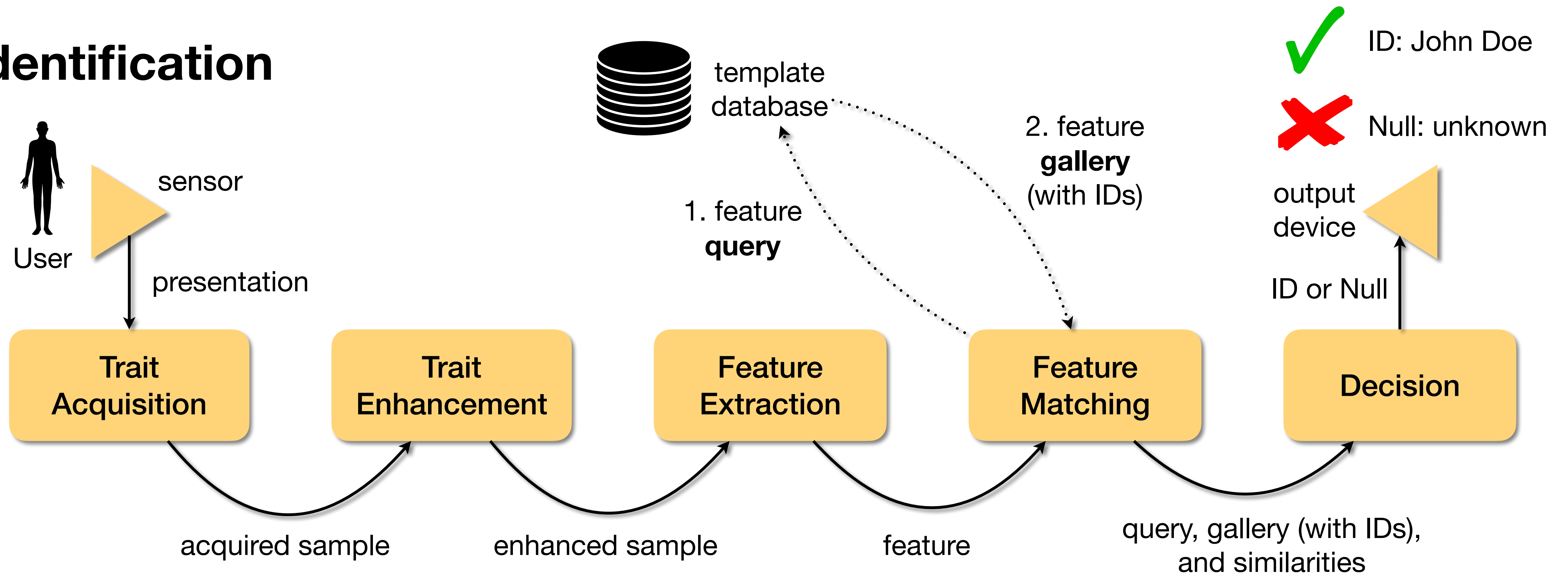

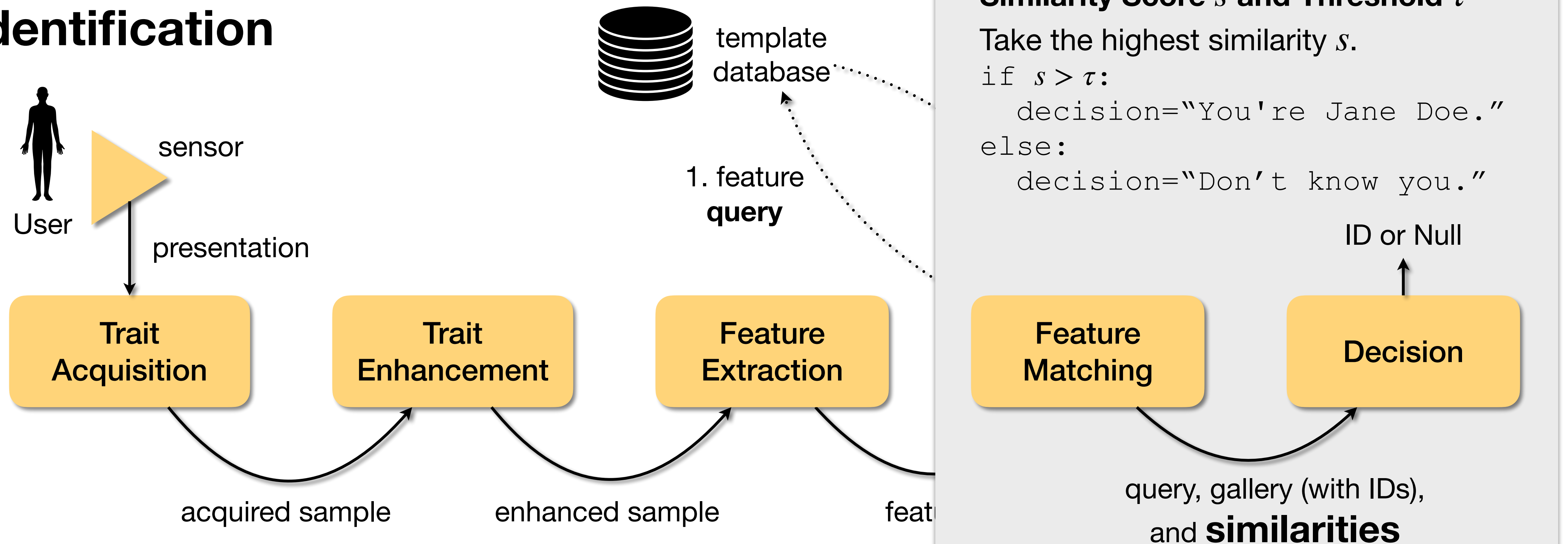Let's see how to compute them!

Metrics

Verification

genuine

impostor

template database

2. template feature

1. ID

sensor

ID

User

presentation

output device

decision

Trait Acquisition	Trait Enhancement	Feature Extraction	Feature Matching	Decision

acquired sample, ID   enhanced sample, ID   feature, ID   similarity (or dissimilarity)

Metrics

Verification

User
ID
sensor
presentation

template database

1. ID

Trait Acquisition → Trait Enhancement → Feature Extraction → Feature Matching → Decision

acquired sample, ID   enhanced sample, ID   feature

Similarity Score s and Threshold τ

```
if s > τ:
    decision="genuine"
else:
    decision="impostor"
```
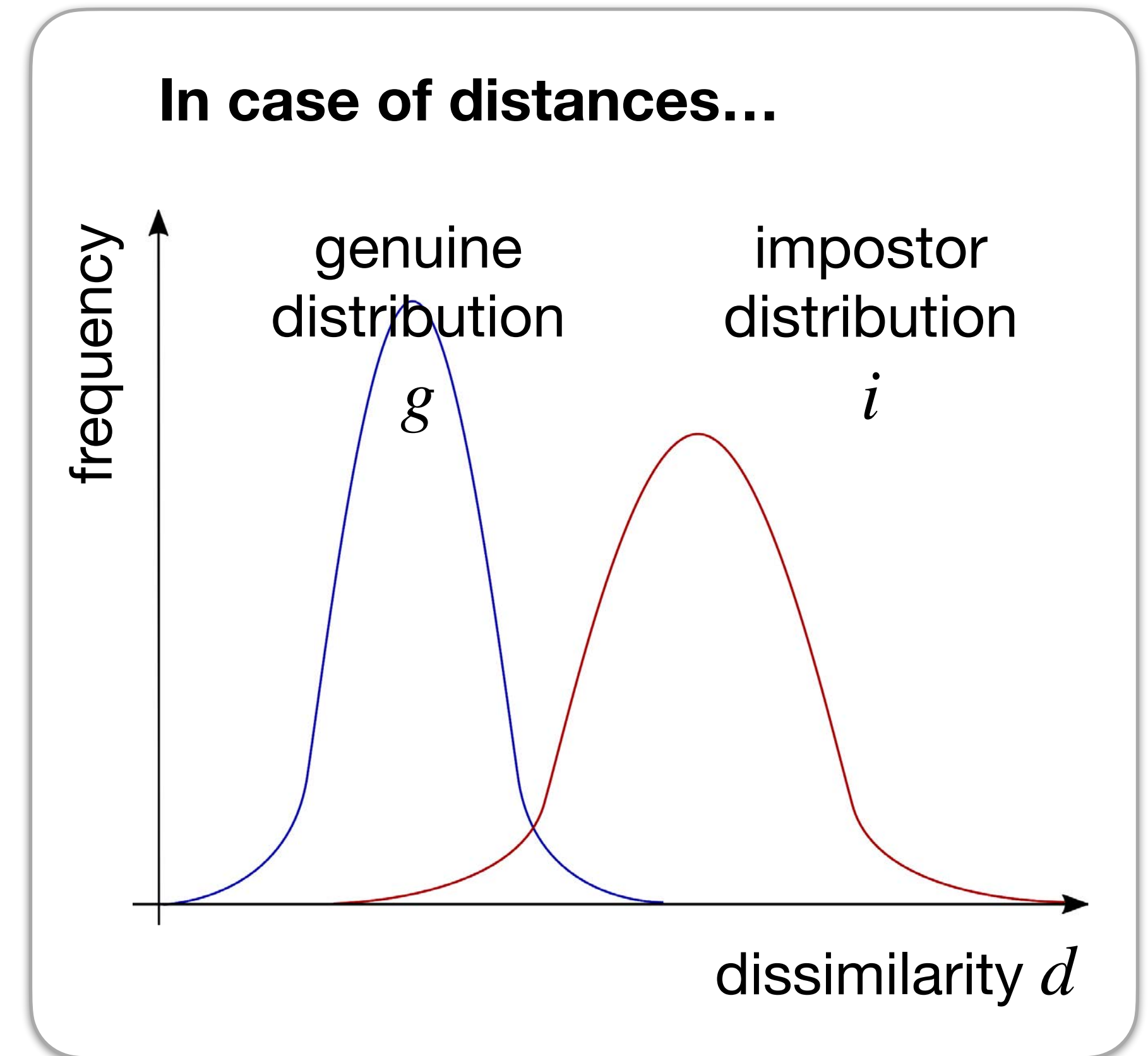
decision

similarity (or dissimilarity)

Metrics

Identification

Metrics

Identification

sensor

User

presentation

template
database

1. feature
query

**Trait
Acquisition**

**Trait
Enhancement**

**Feature
Extraction**

**Feature
Matching**

Decision

acquired sample

enhanced sample

feat...

query, gallery (with IDs),
and **similarities**

ID or Null

Similarity Score s and Threshold τ
Take the highest similarity s.
```
if s > τ:
    decision="You're Jane Doe."
else:
    decision="Don't know you."
```

Metrics

impostor distribution i

genuine distribution g

frequency

similarity s

In case of distances...

frequency

genuine distribution g

impostor distribution i

dissimilarity d

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Metrics

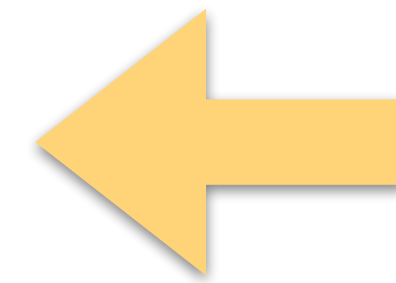$$FNM(\tau) = \int_{-\infty}^{\tau} g(s) \ ds$$
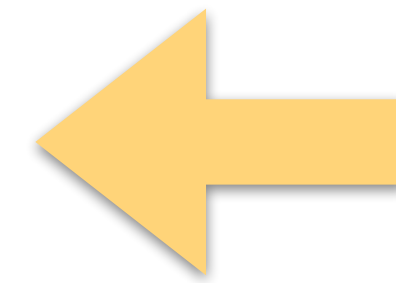
$$FM(\tau) = \int_{\tau}^{\infty} i(s) \ ds$$

Metrics

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

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

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

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

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

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Metrics

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

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

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

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

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.
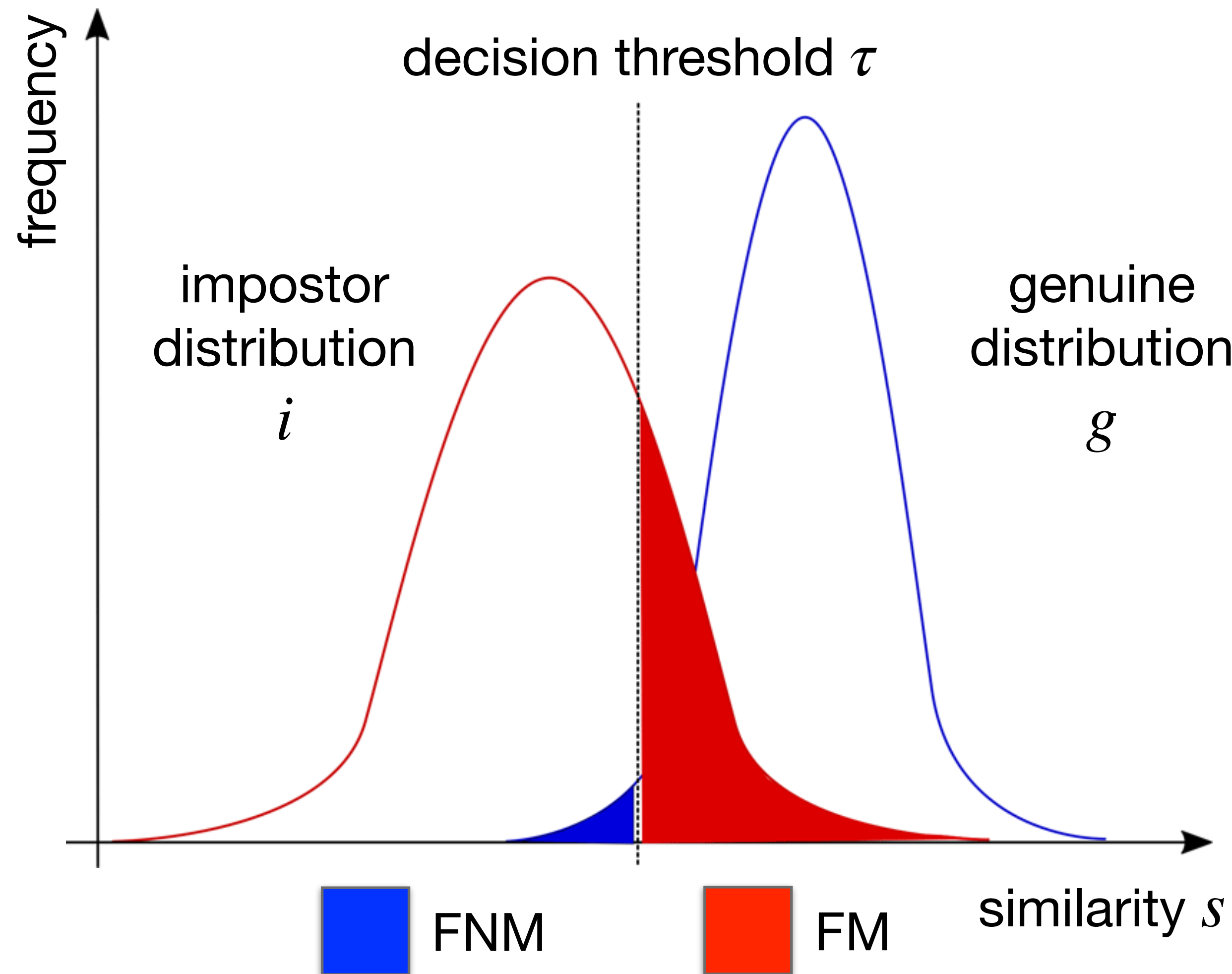Is it good?

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.
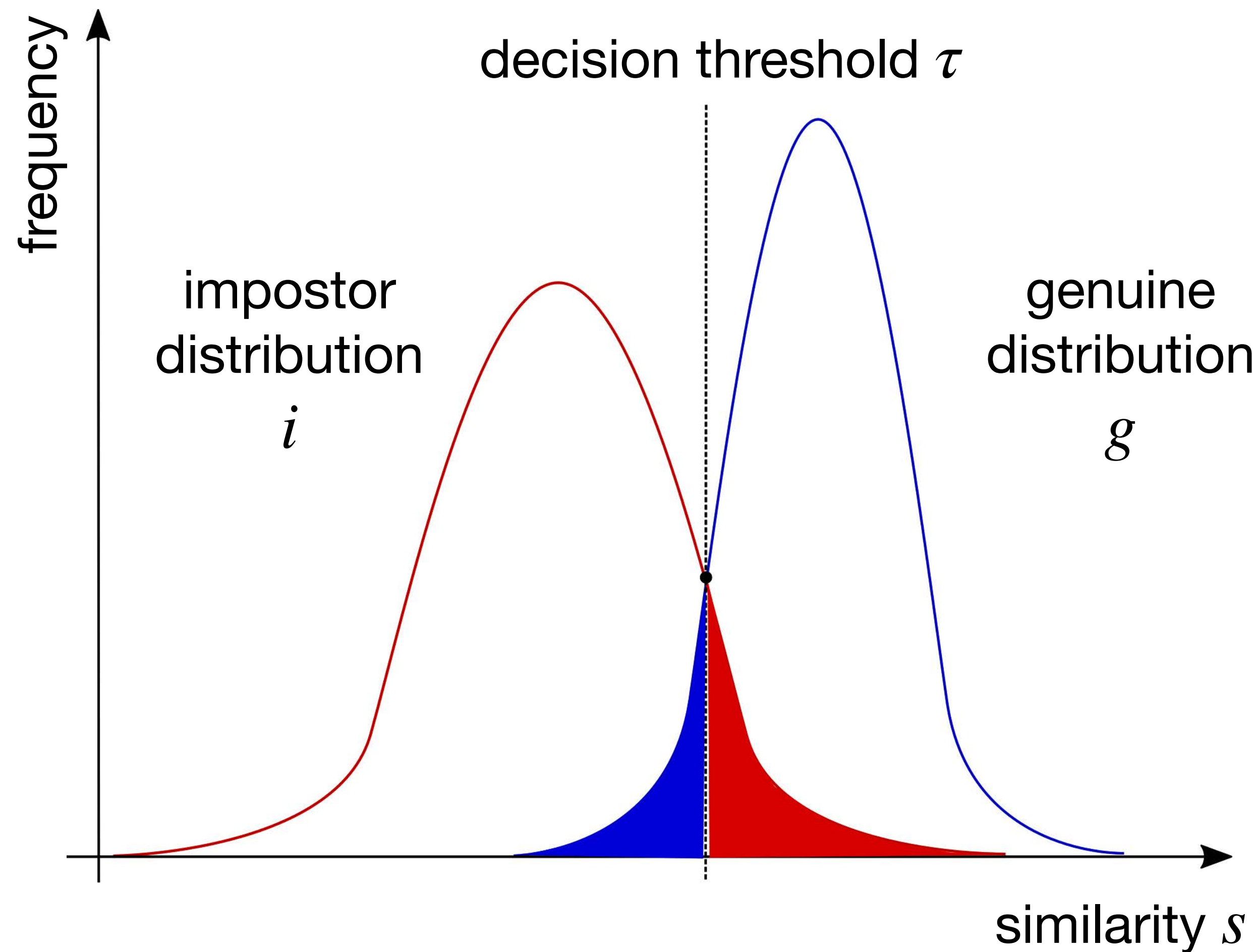Increases intrusion probability, though.

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

Metrics

frequency

decision threshold τ

impostor
distribution
i

genuine
distribution
g

similarity s

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.

What to do when system A has smaller FNMR
than system B, but larger FMR (or vice-versa)?
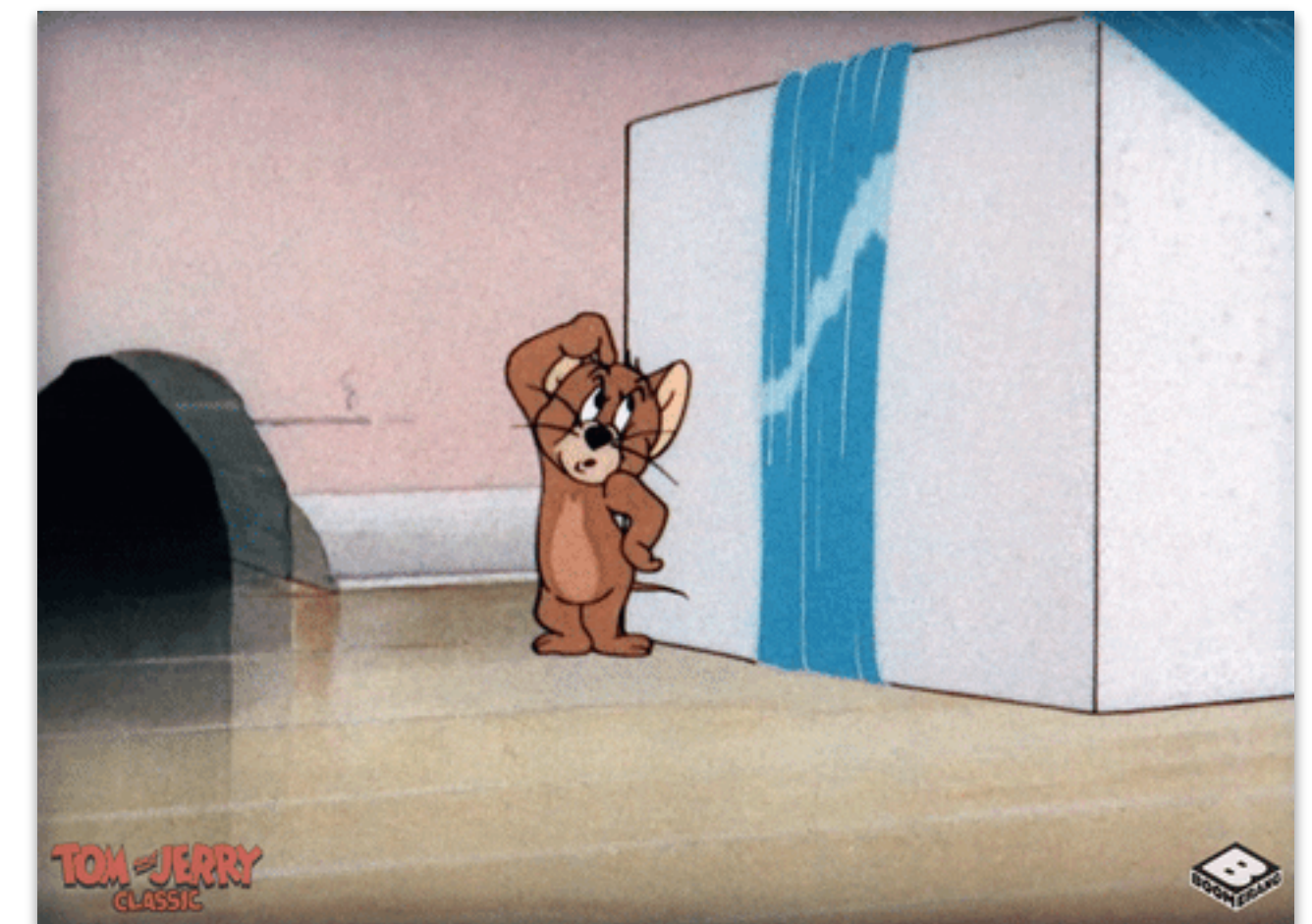
Metrics

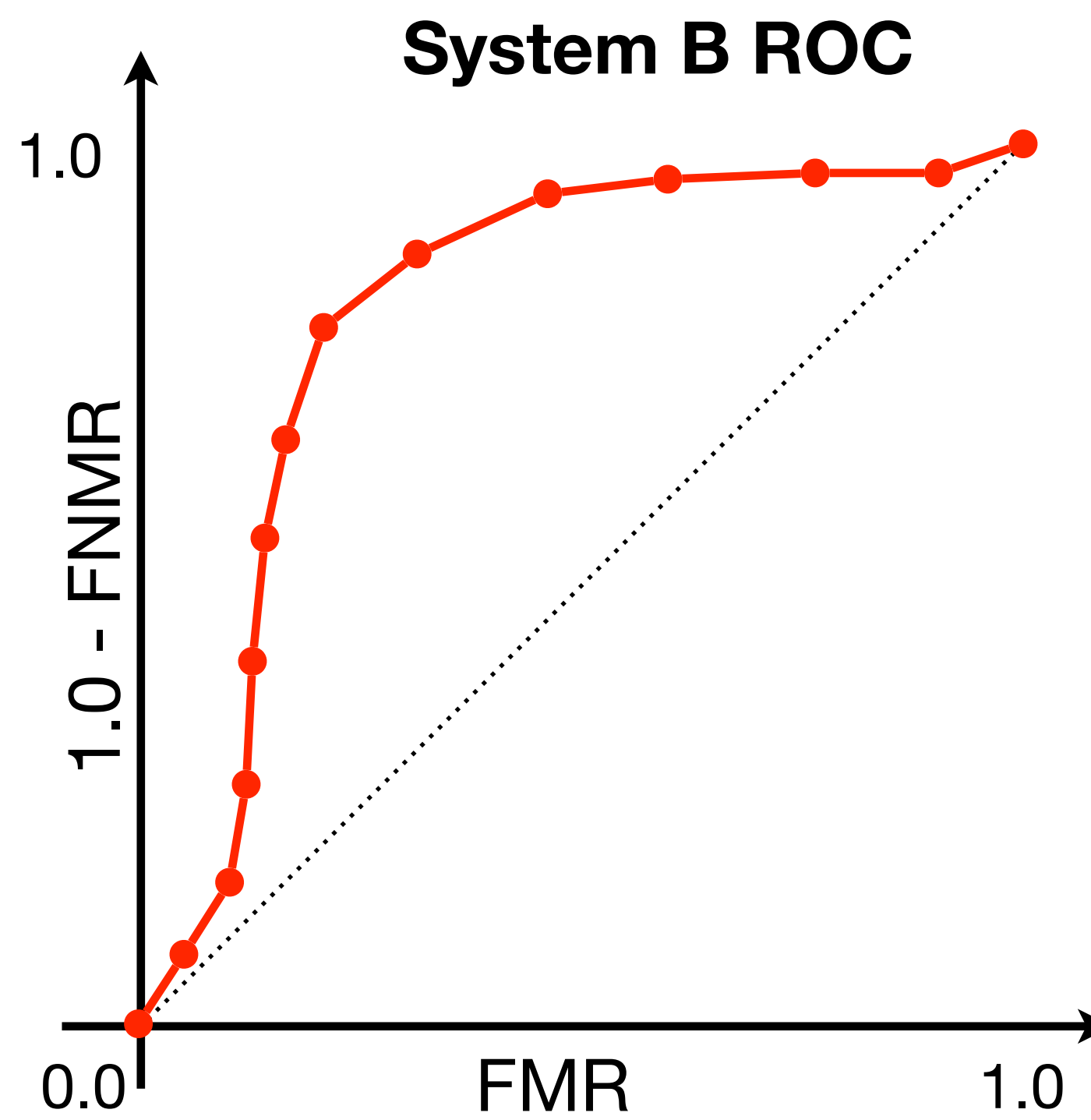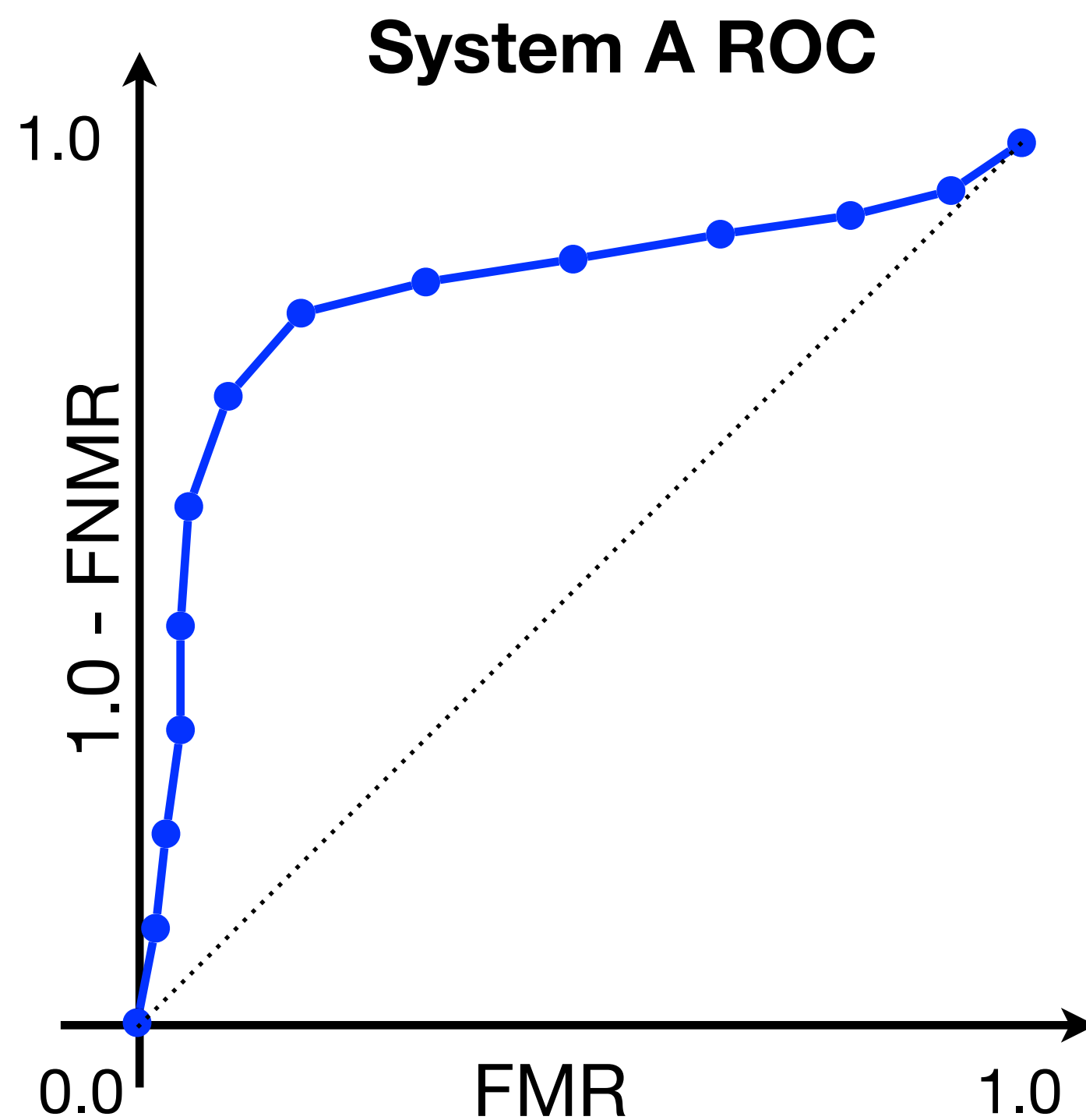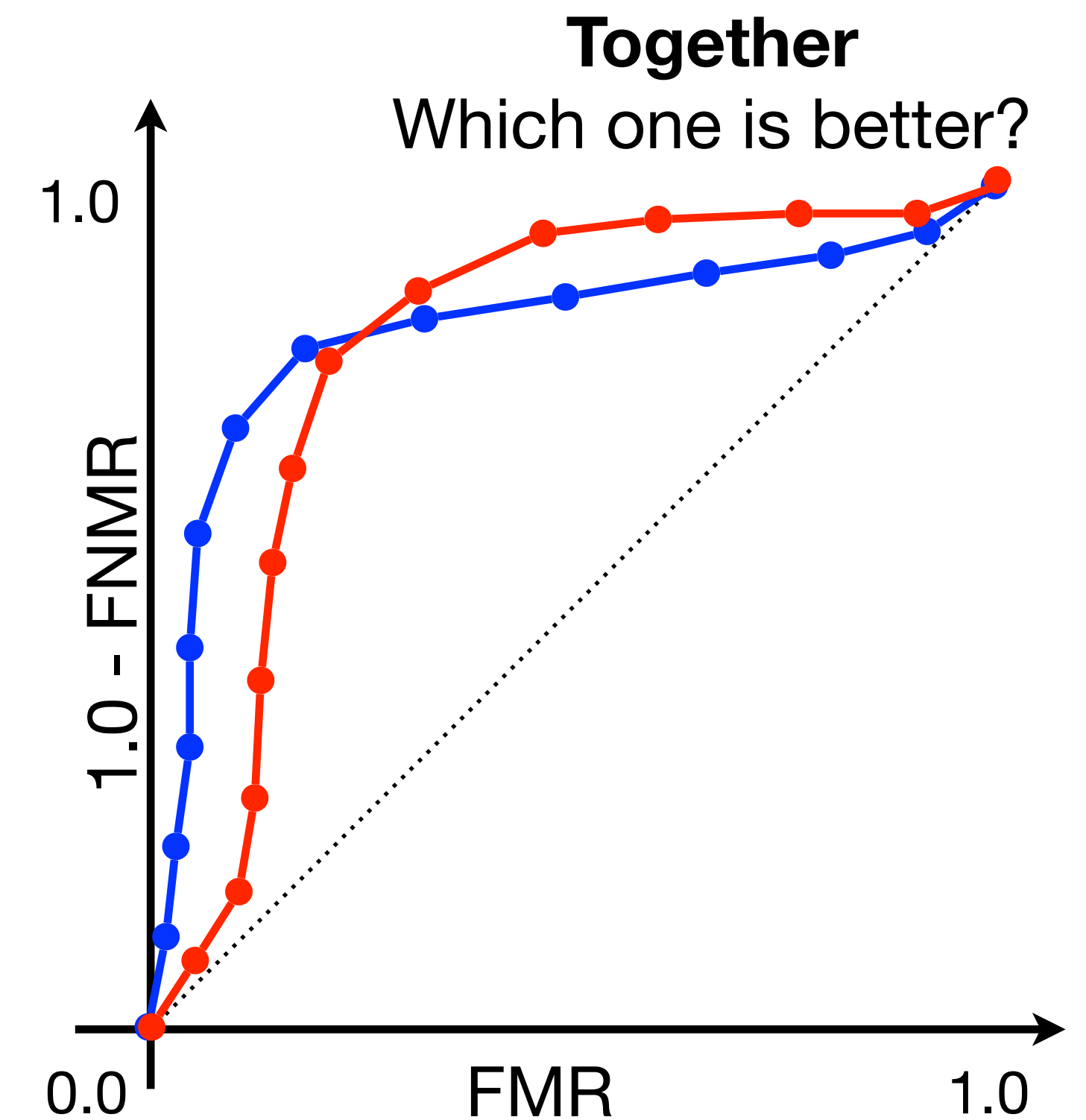**How to compare two different systems?**
Biometric systems *A* and *B.*

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

Metrics

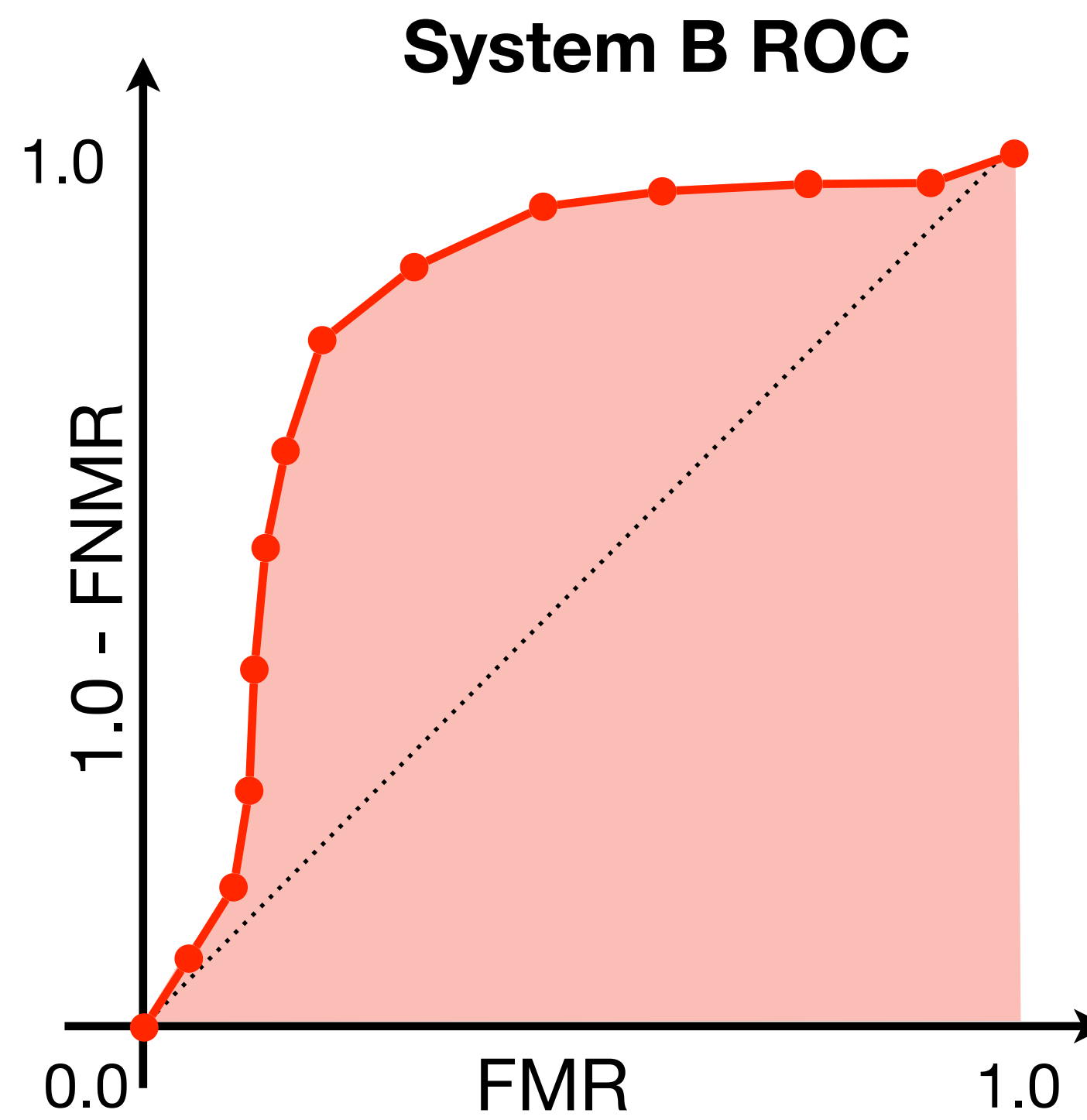**How to compare two different systems?**
Biometric systems *A* and *B.*
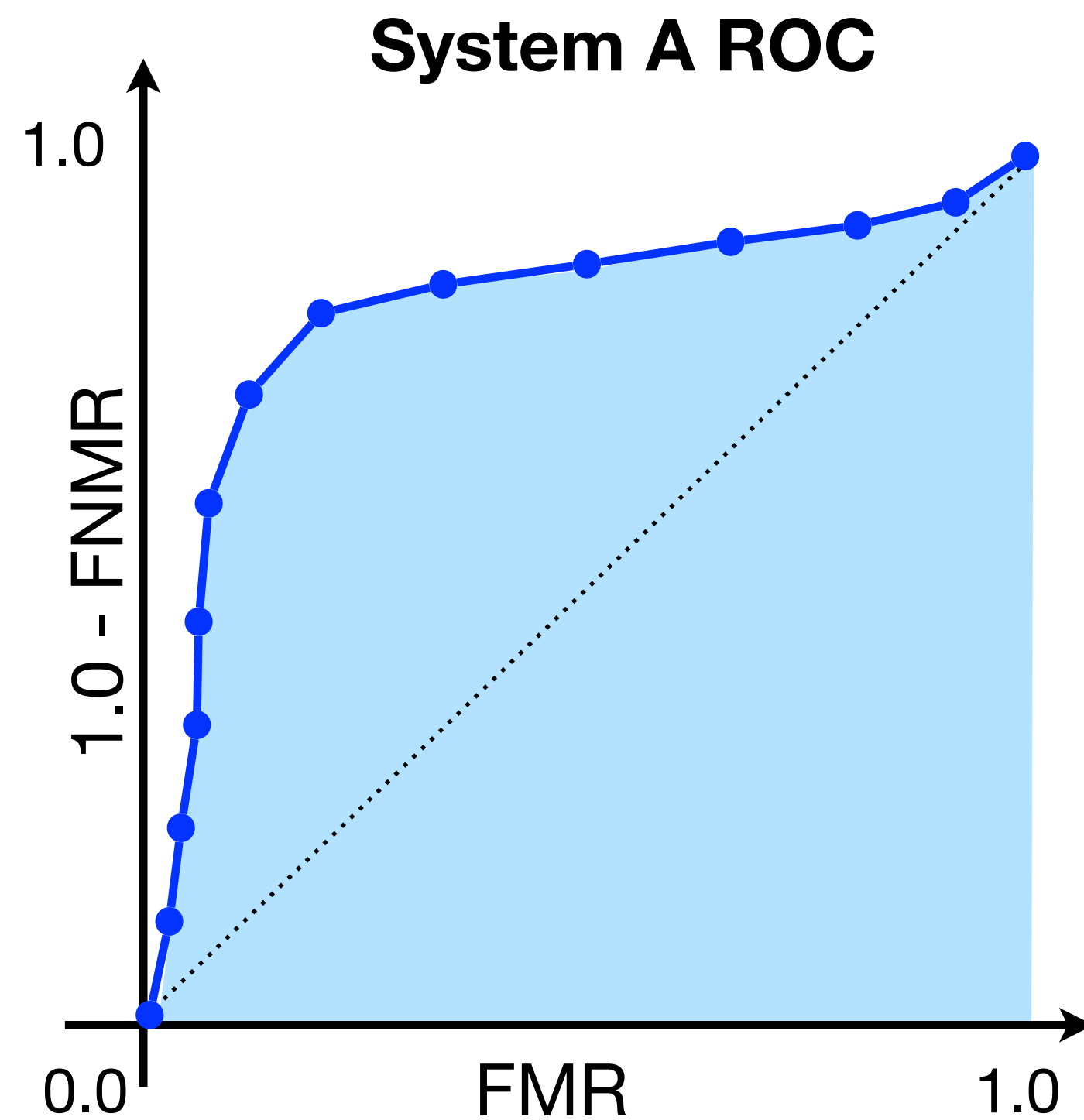
Compute FMR and FNMR for a variety of thresholds.

System A ROC

System B ROC

Together
Which one is better?

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Metrics

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

System A ROC

System B ROC

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

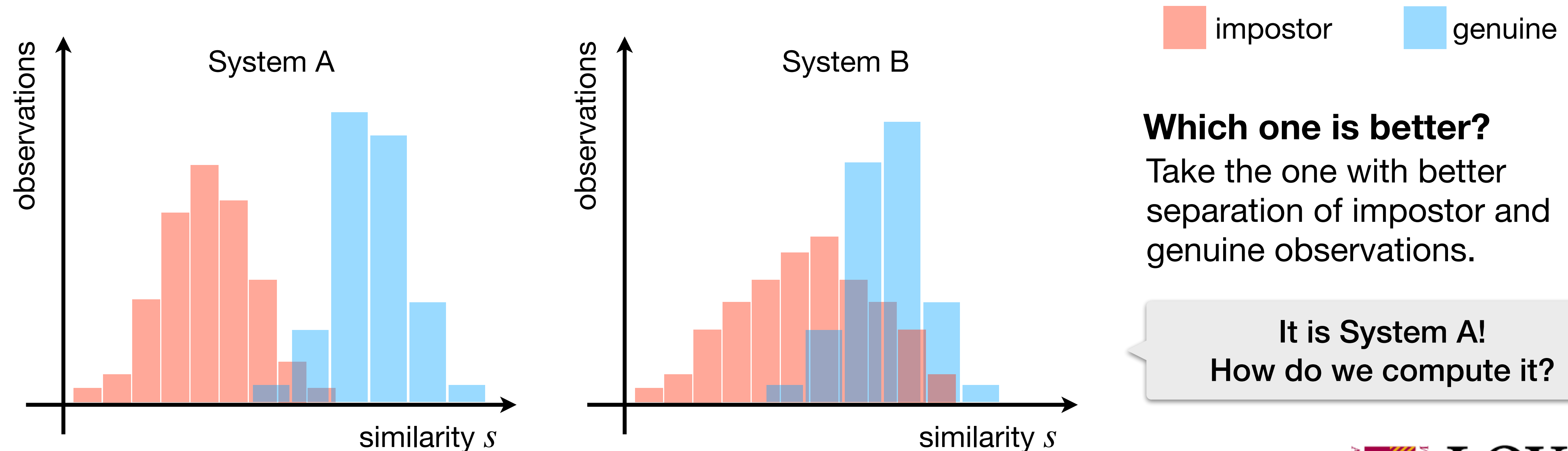# Metrics

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,
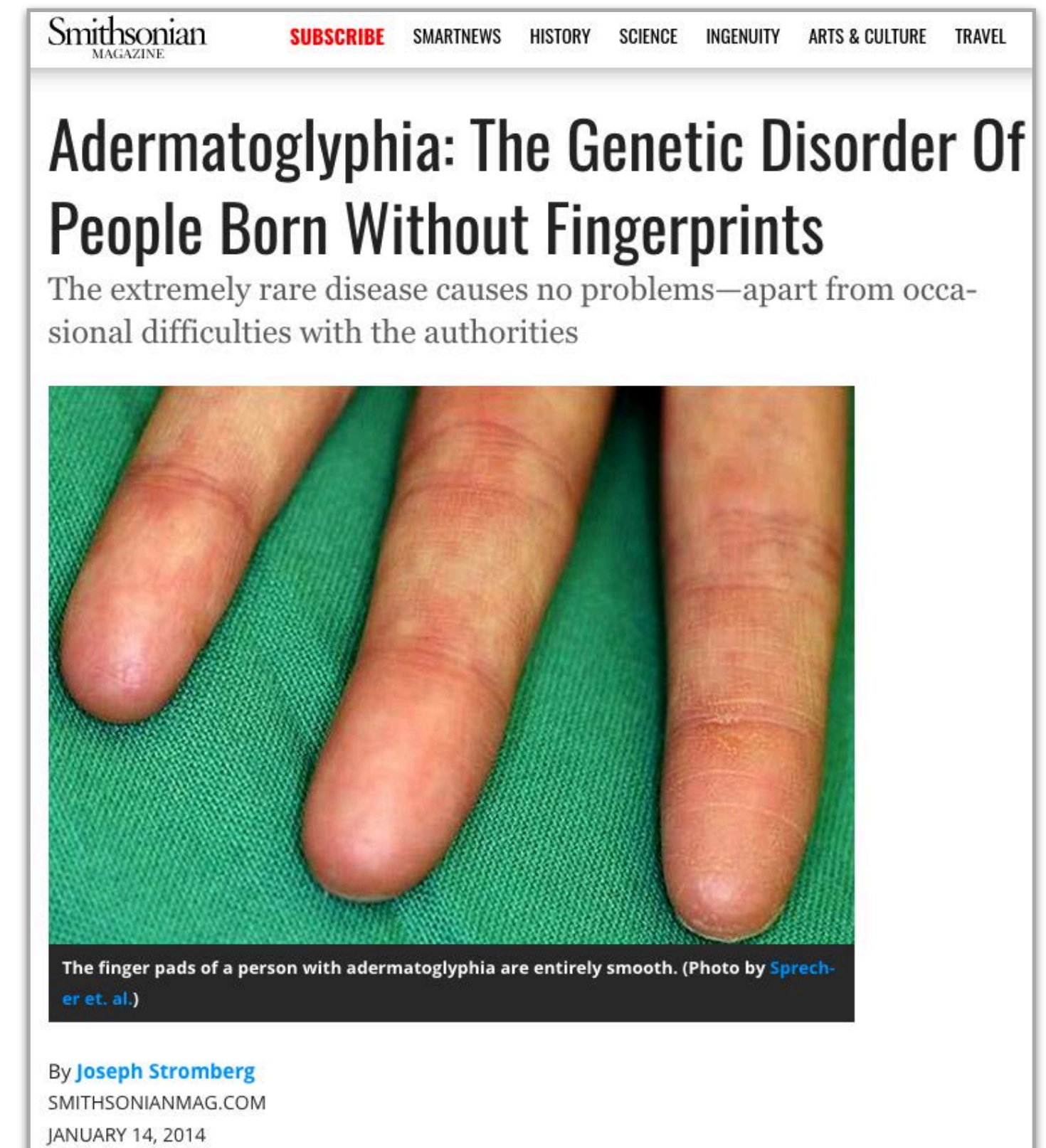the larger the value of d-prime.

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.

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Adermatoglyphia: The Genetic Disorder Of People Born Without Fingerprints
The extremely rare disease causes no problems—apart from occasional difficulties with the authorities

The finger pads of a person with adermatoglyphia are entirely smooth. (Photo by Sprecher et. al.)

By Joseph Stromberg
SMITHSONIANMAG.COM
JANUARY 14, 2014

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

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Metrics

Other Metrics (3/4, 4/4)

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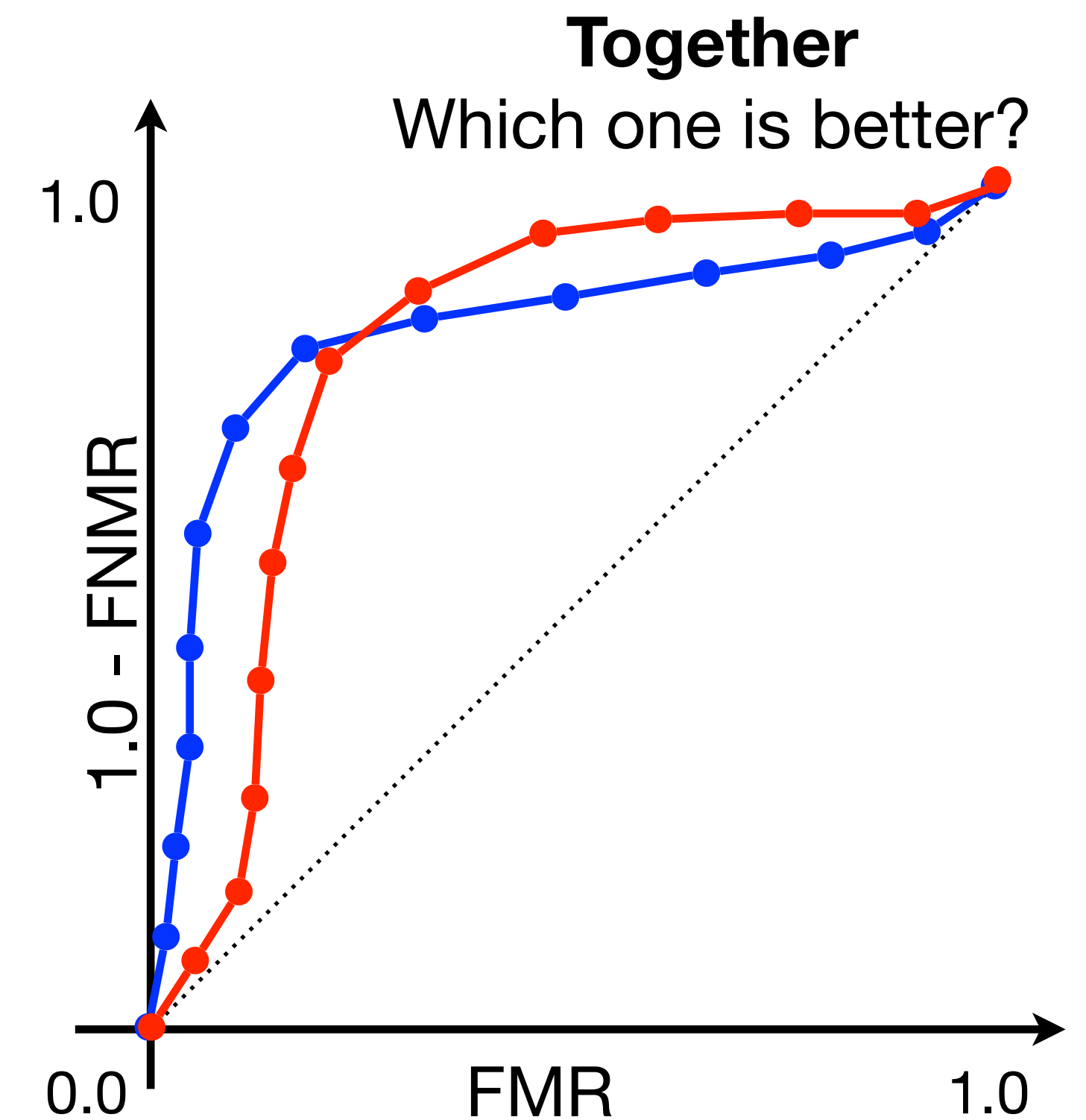TNMR = 1.0 - FMR

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.

System A ROC

1.0 – FNMR

0.0 — FMR — 1.0

System B ROC

1.0 – FNMR

0.0 — FMR — 1.0

Together
Which one is better?

1.0 – FNMR

0.0 — FMR — 1.0

Metrics

How to compare two different systems?
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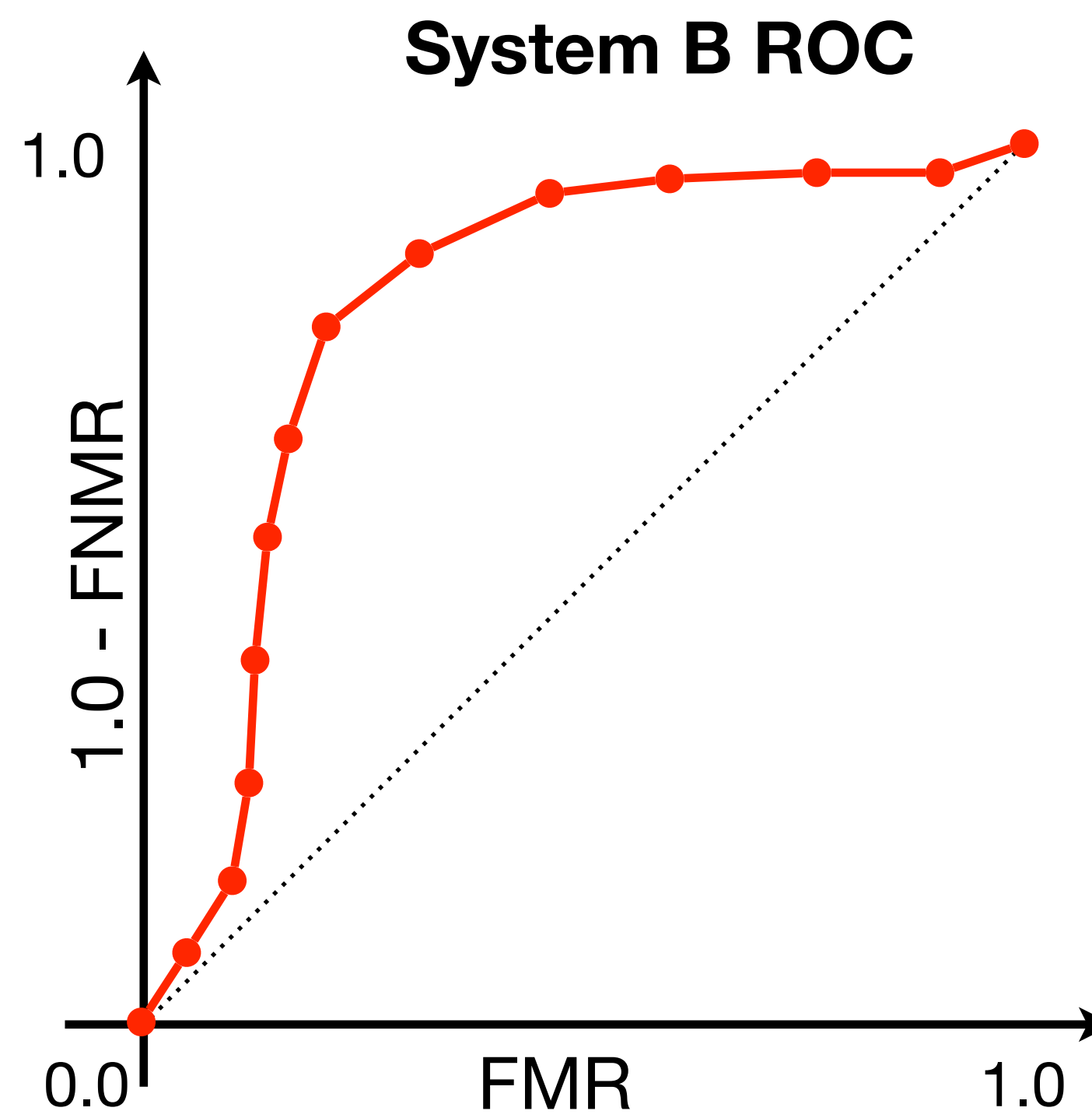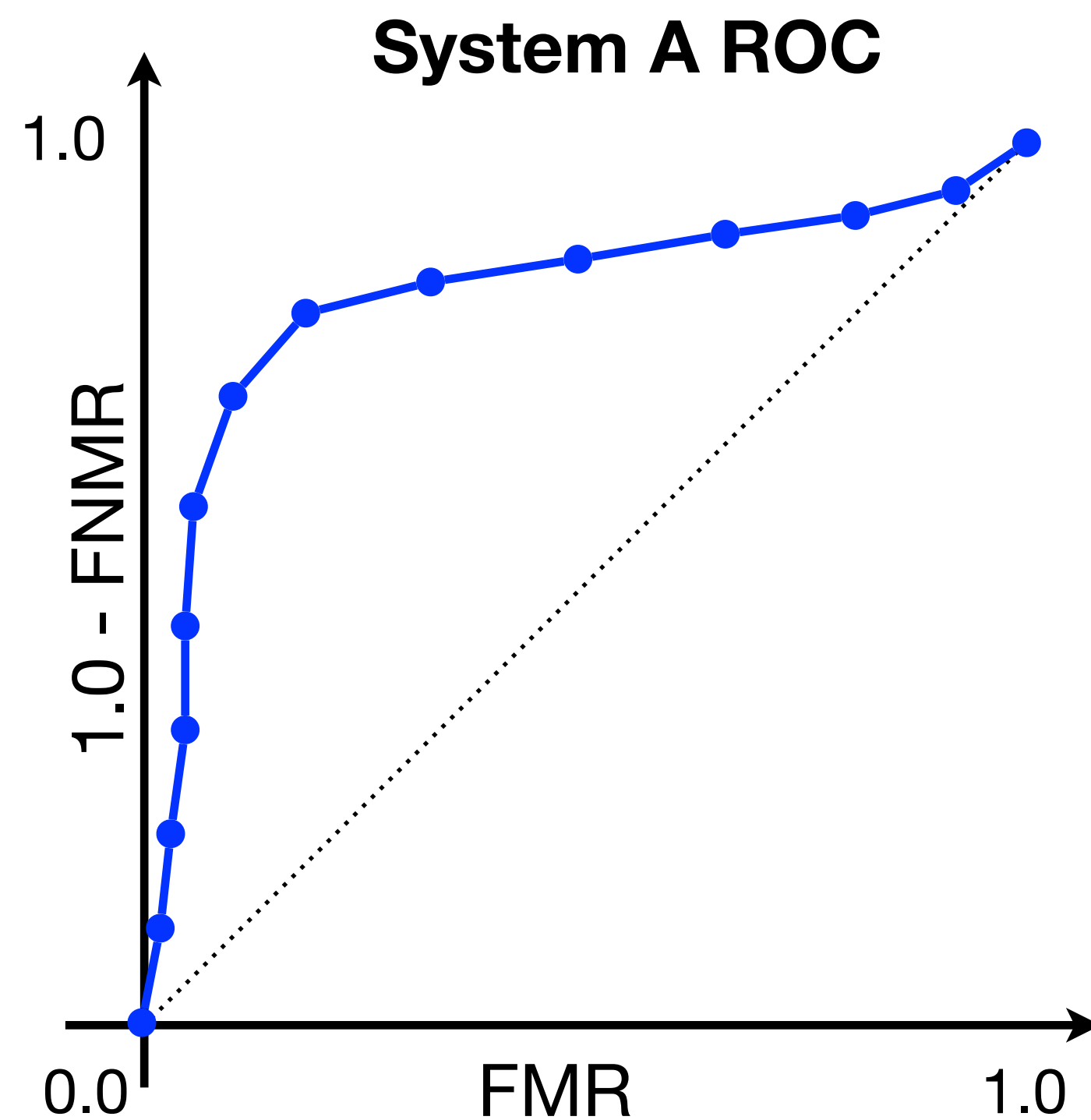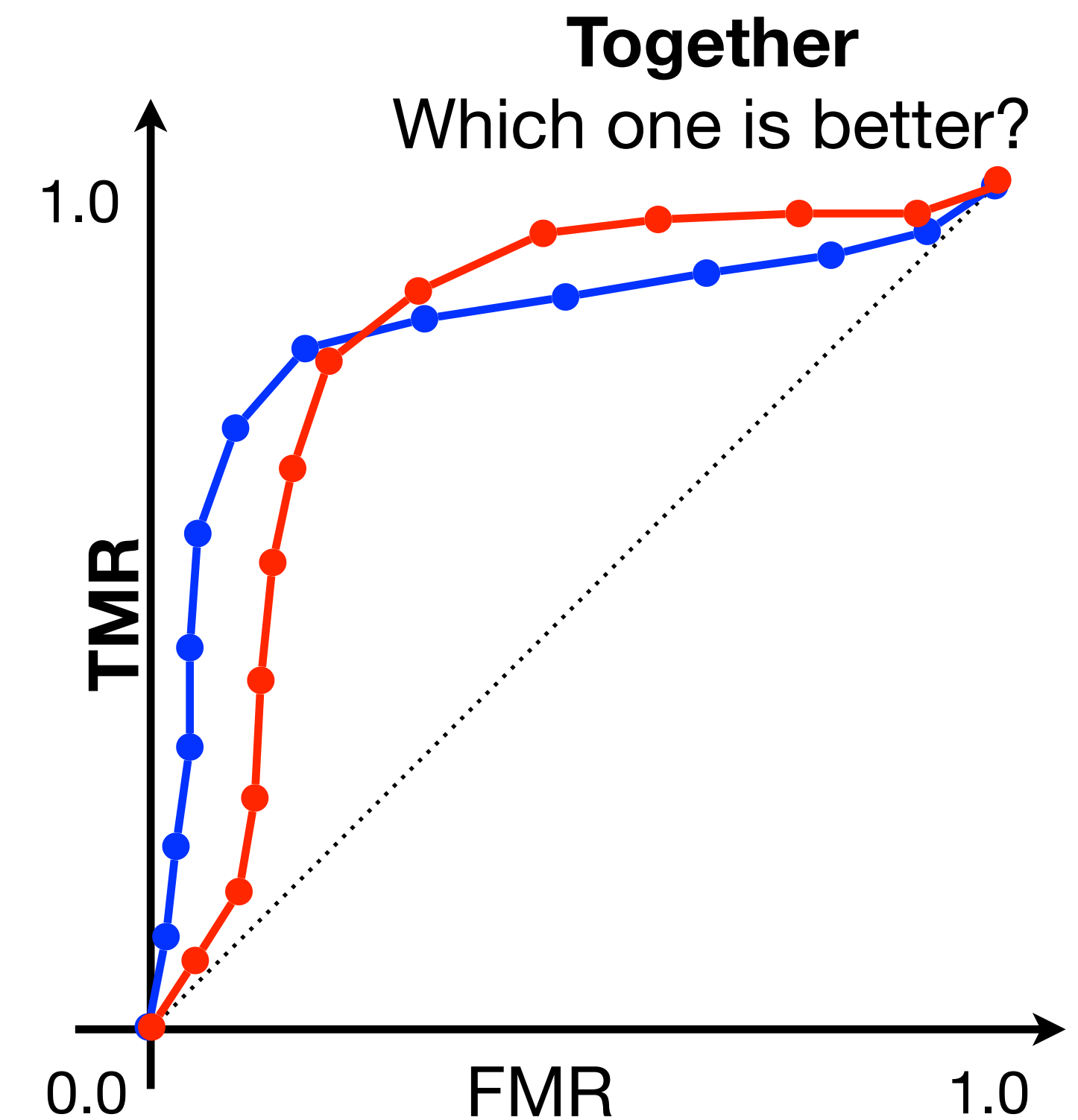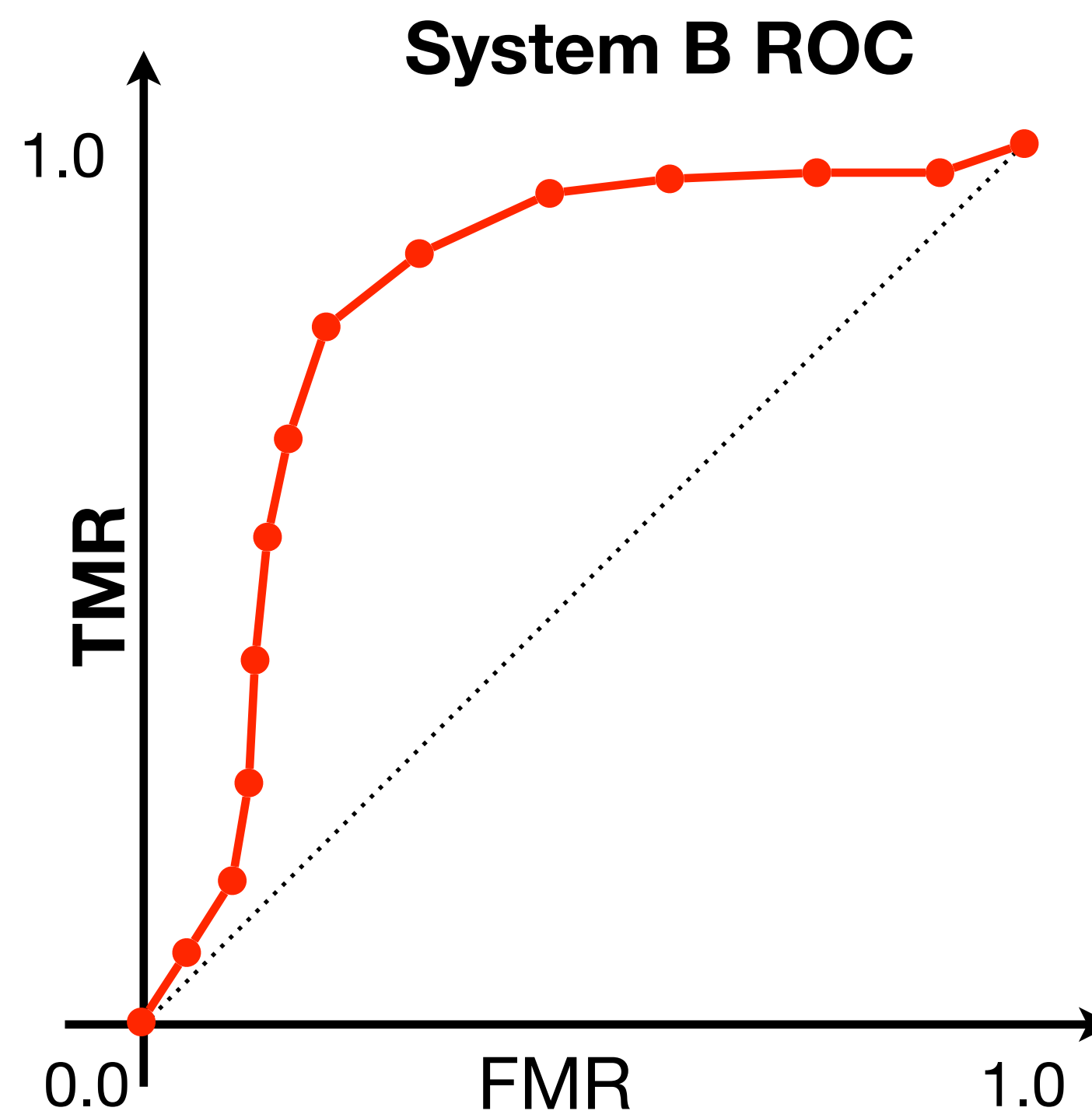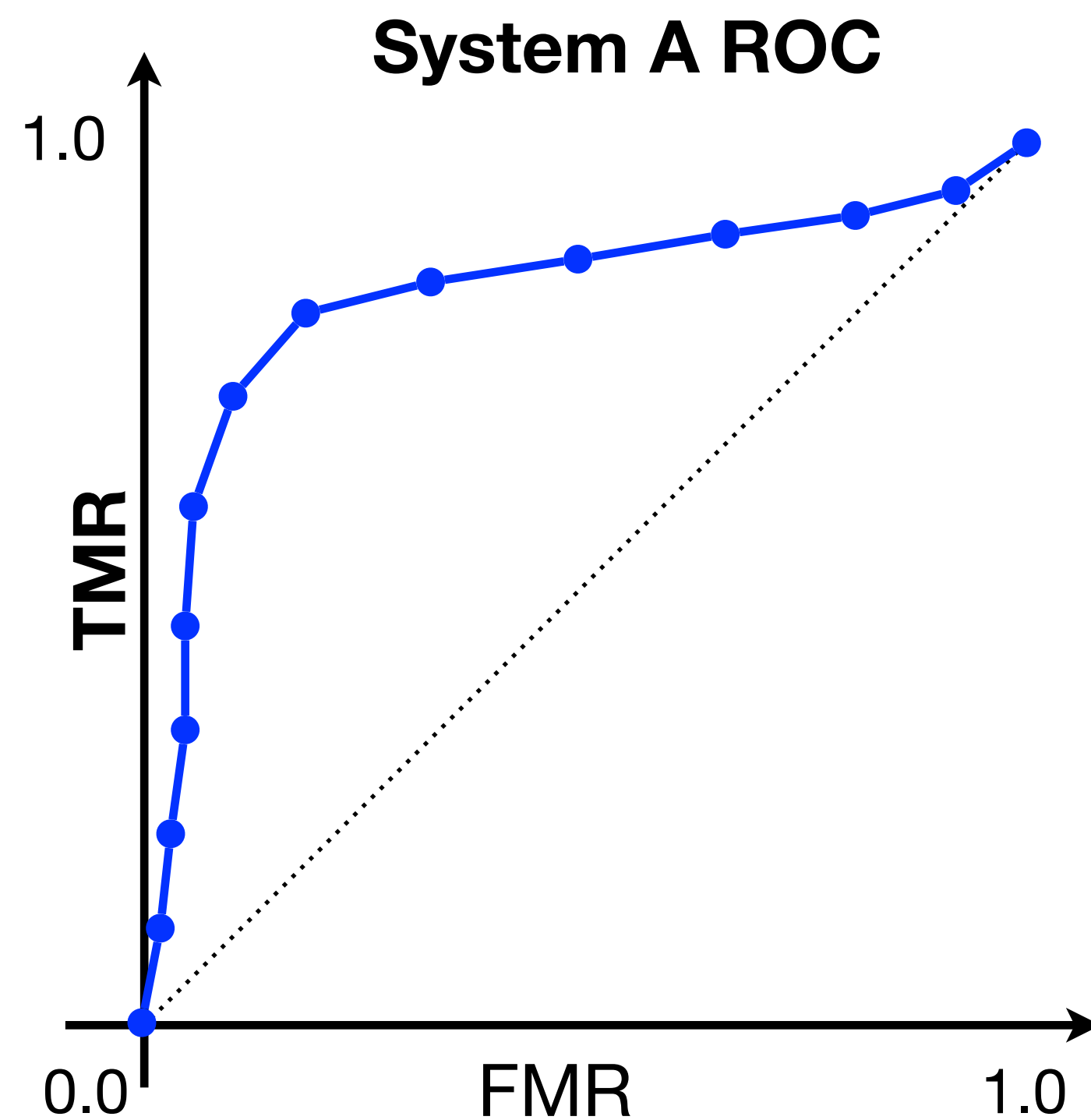
What's Next?

First Coding Day
Implementation of metrics.

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

Be ready! :)
Tools: Google Colab.