Biometric Performance

Biometric Systems (DTU 02238)

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Session 7 and 8

Overview Biometric Performance

Structure of this session

- Issues in Performance Tests
- Fundamental Metrics
- Reporting and Visualisation
- Standards

Categorization of Biometric Systems

Costs

- Installation- and maintenance costs

Operating expense

- Duration (transaction time) and complexity of operation
- Adaptation time

Biometric performance

- How precise does the system recognize individuals?
- What are the error rates?

Presentation Attack Detection (PAD)

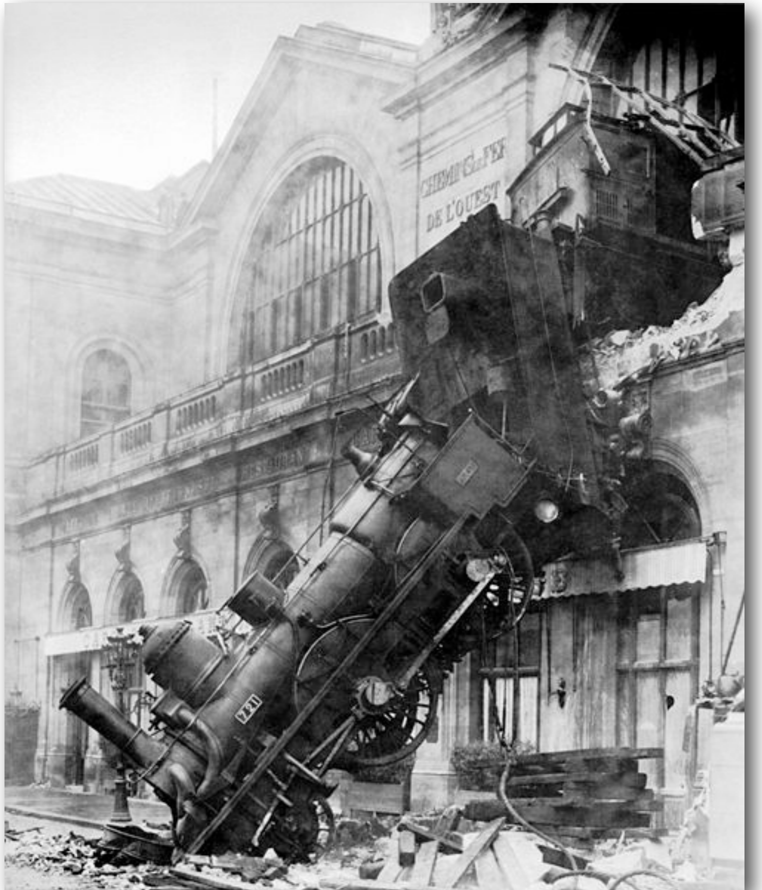
- Does the system detect artefacts
  of biometric characteristics (a.k.a fakes)

Issues in Performance Tests

Performance Test and Errors

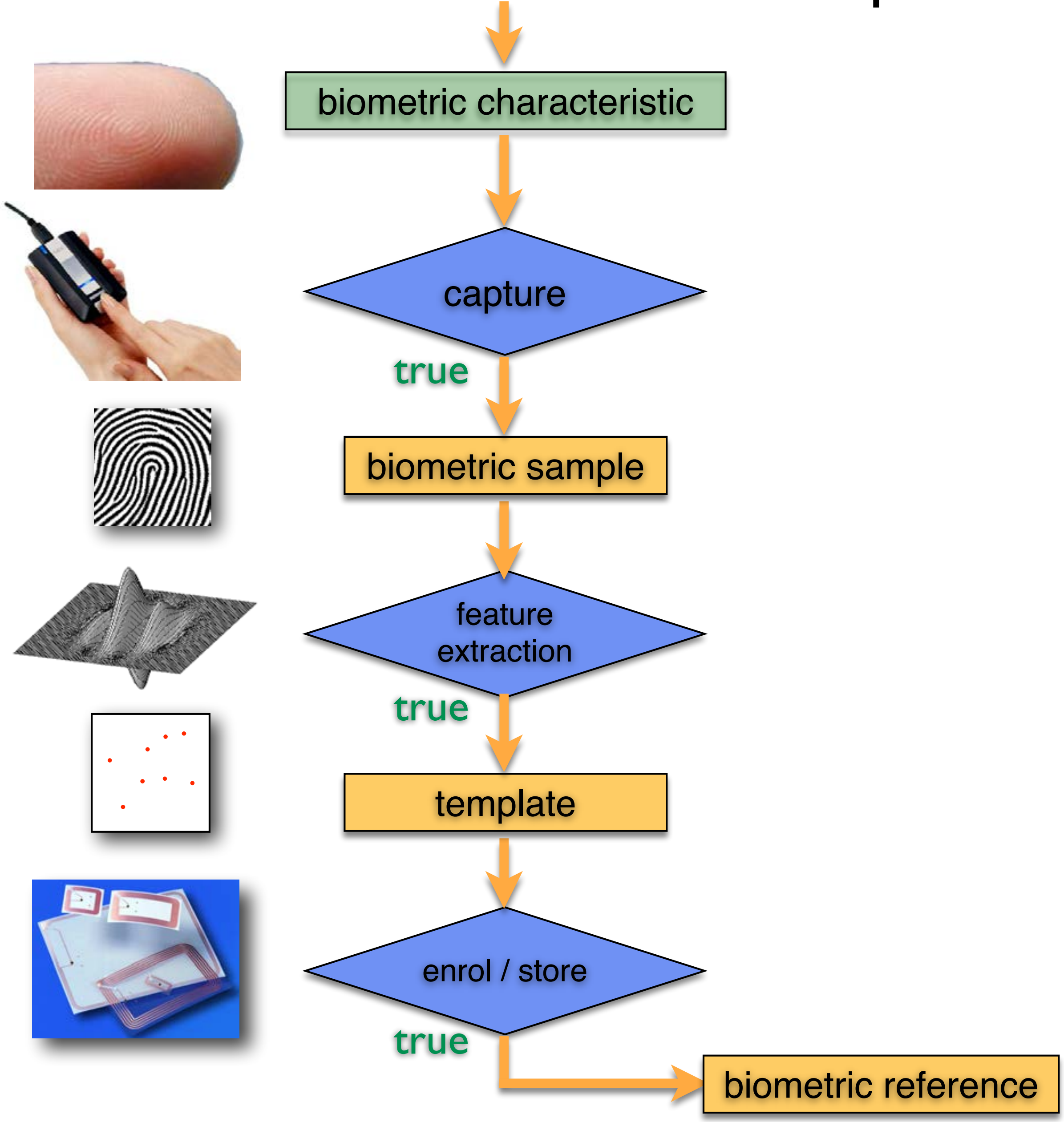
Why measure failures?

- Murphy‘ Law teaches us:
  „Whatever can go wrong, will go wrong.“
  - It is just a matter of the point in time ...
  - ... and the likelihood
    that a failure happens
  - There are small failures ...
  - ... and larger disasters



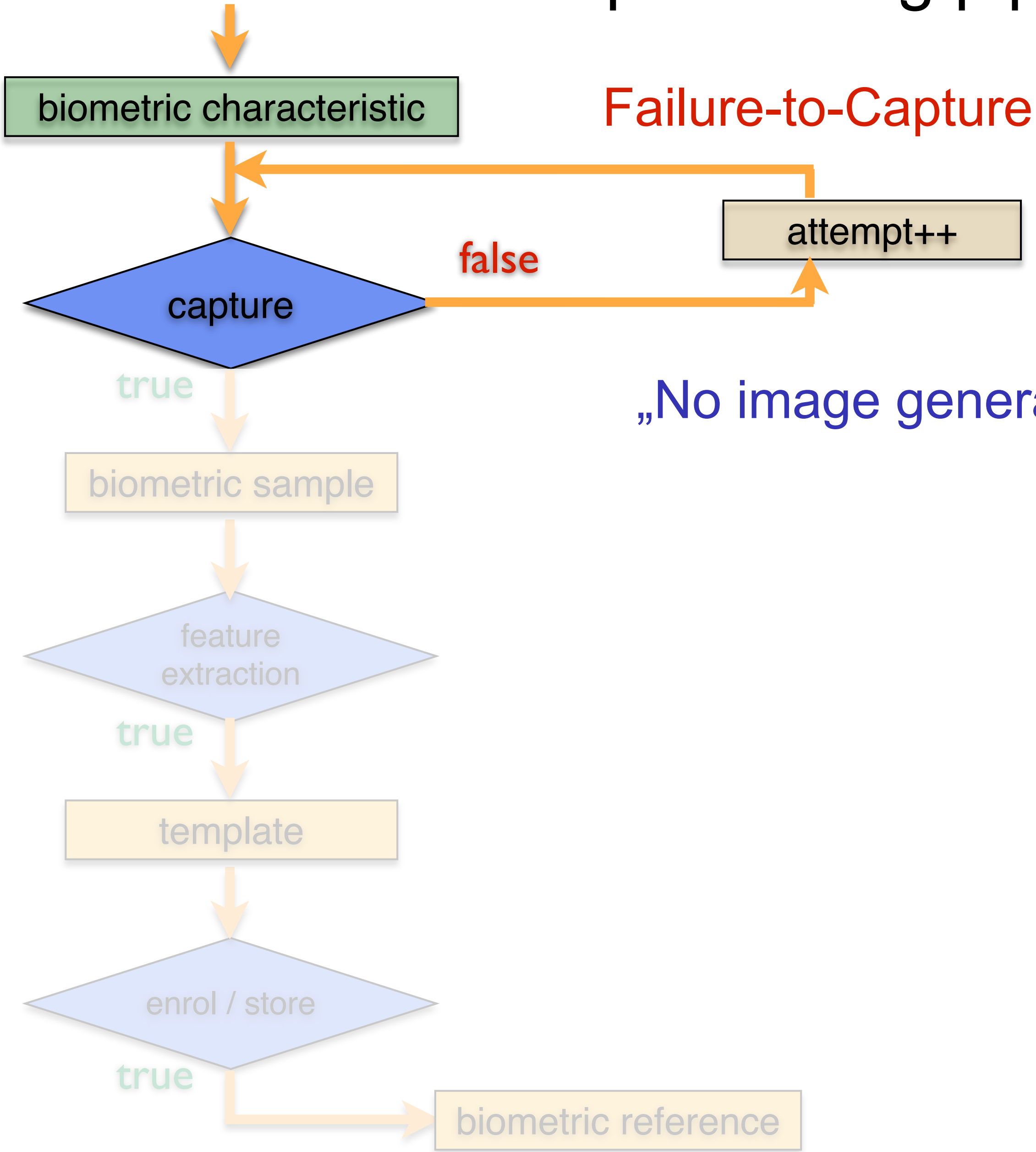
Failures

Potential failures in a biometric processing pipeline



Failures

Potential failures in a biometric processing pipeline

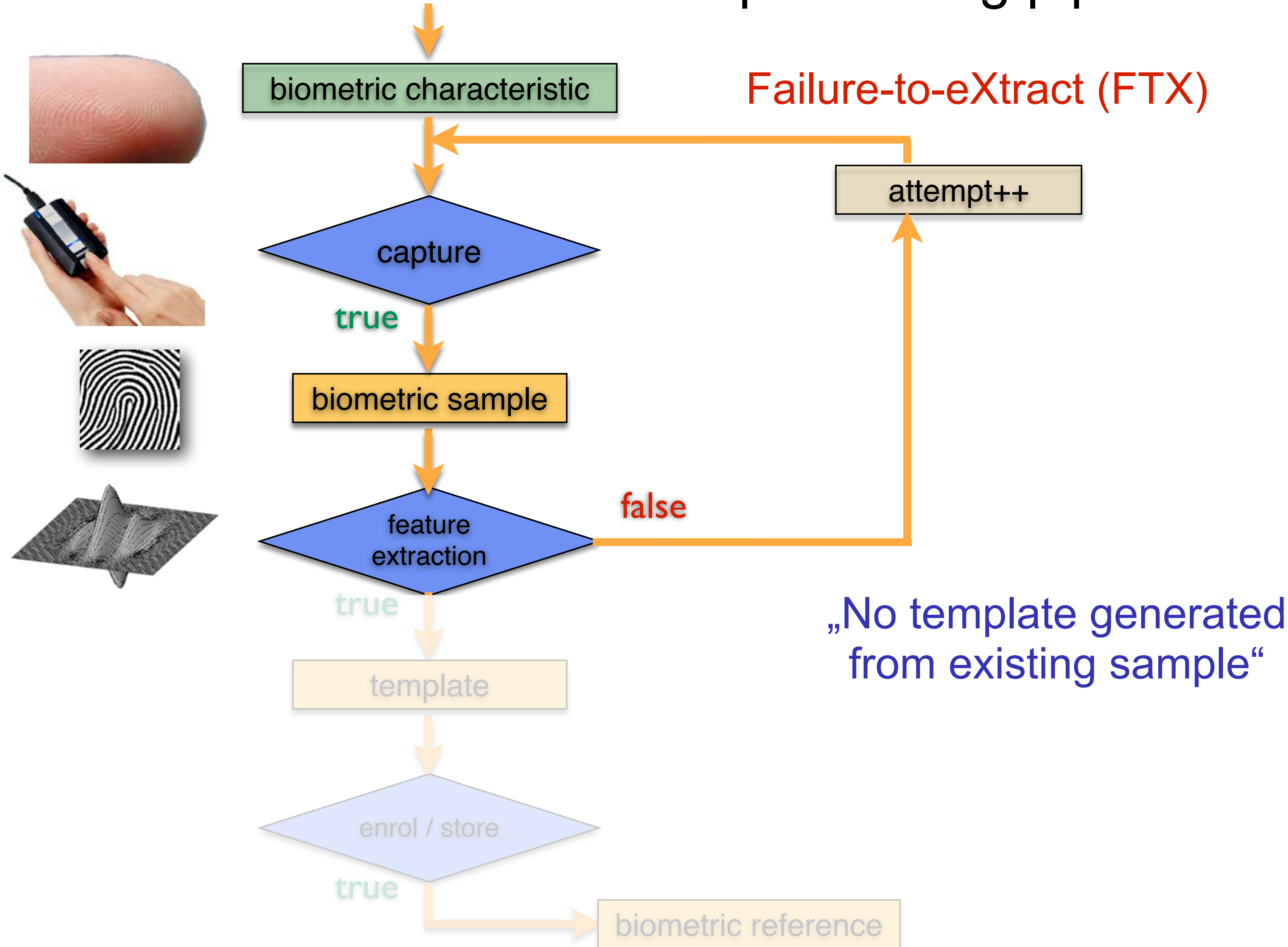


Failure-to-Capture (FTC)

„No image generated“

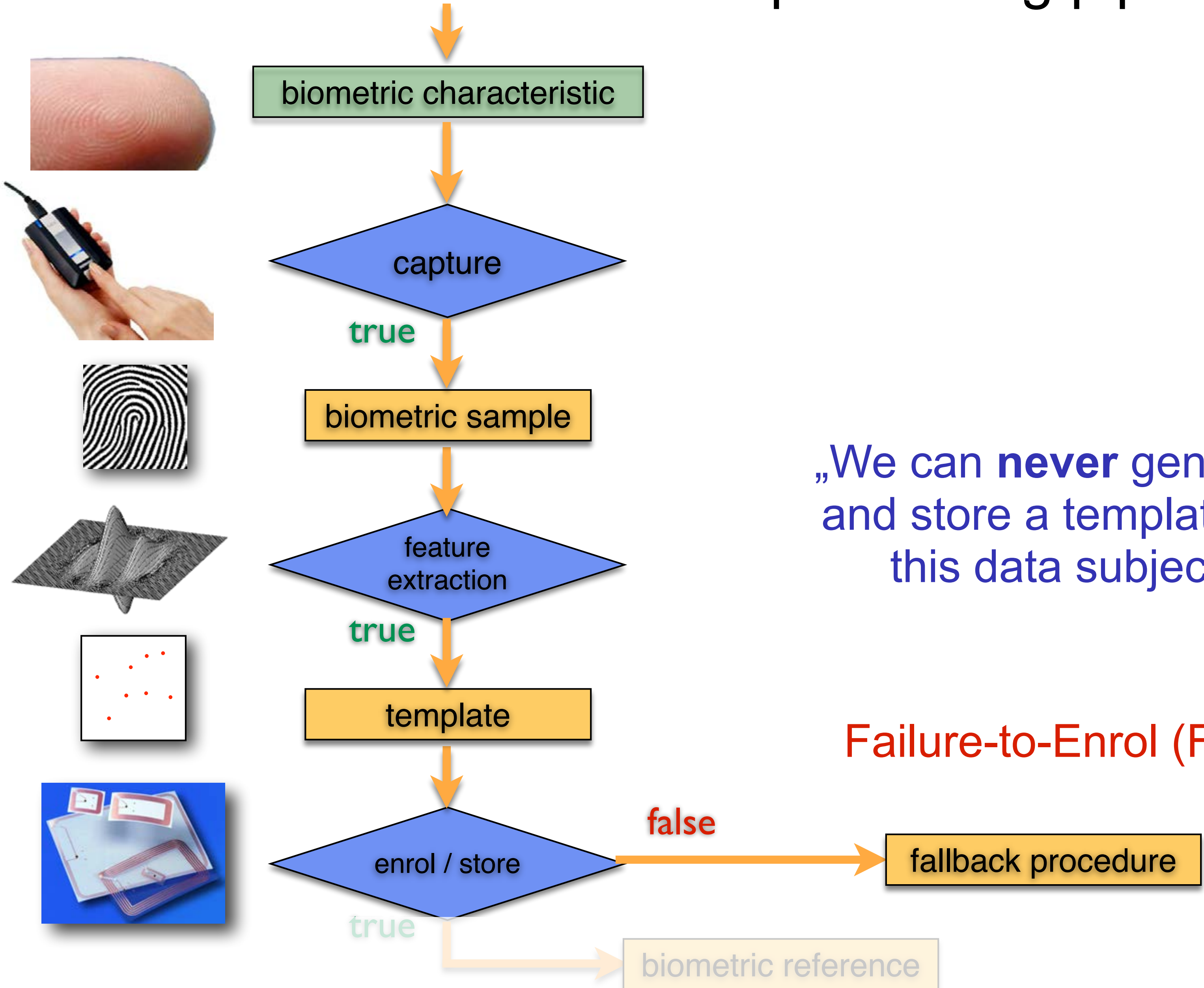
Failures

Potential failures in a biometric processing pipeline



Failures

Potential failures in a biometric processing pipeline



„We can **never** generate and store a template for this data subject“

Failure-to-Enrol (FTE)

Performance Metrics

Failure-to-Capture Rate (FTCR)

aligned to ISO-HBV: *proportion of failures of the biometric capture process to produce a captured biometric sample of the biometric characteristic of interest*

$$FTCR = \frac{N_{tca} + N_{nsq}}{N_{tot}}$$

where

N_{tca} is the number of terminated capture attempts

N_{nsq} is the number of images created with insufficient sample quality

N_{tot} is the total number of capture attempts

Definition of FTC: https://www.iso.org/obp/ui/#iso:std:iso-iec:2382:-37:ed-2:v1:en:term:3.9.5

Performance Metrics

Failure-to-eXtract Rate (FTXR)

Def: *proportion of failures of the feature extraction process to generate a template from the captured biometric sample*

$$FTXR = \frac{N_{ngt}}{N_{sub}}$$

where

N_{ngt} is the number of cases where no template was generated

N_{sub} is the total number of biometric samples being submitted to the feature extraction

Performance Metrics

Failure-to-Enrol Rate (FTER)

aligned to ISO-HBV: *proportion of a specified set of biometric enrolment transactions that resulted in a failure to create and store a biometric enrolment data record*

$$FTER = \frac{N_{nec}}{N}$$

where

N_{nec} is the number of cases where the biometric characteristic of the subject cannot be captured at all

N is the total number of subjects intended to be enrolled in the biometric application

Definition of FTER https://www.iso.org/obp/ui/#iso:std:iso-iec:2382:-37:ed-2:v1:en:term:3.9.7

Performance Metrics

Failure-to-Acquire Rate (FTAR)

aligned to ISO-HBV: *proportion of a specified set of biometric acquisition processes that were failure to accept for subsequent comparison the output of a data capture process*

Note: This is caused by either a FTCR or a FTXR in the in the verification process. No probe feature vector.

$$FTAR = FTCR + FTXR * (1 - FTCR)$$

Definition of FTAR https://www.iso.org/obp/ui/#iso:std:iso-iec:2382:-37:ed-2:v1:en:term:3.9.4

Issues in Performance Tests

Biometric performance for a failure to occur

- Error rates are specified in proportions
- Assumes random nature.
  - is that assumption correct?

What else can cause failures?

- Systematic errors caused by:
  - violation of persistence property
    - variations of the observed biometric characteristic
    - ageing, spontaneous variations
  - environmental factors
    - illumination, background noise, …
  - quality of the samples

Issues in Performance Tests

Validate the test data - before you fix the corpus

- Control the quality of the corpus
  - „ground truth“ could be error prone
  - empty chair

- Examples of typical testing mistakes
  - fingerprint images assigned to the wrong subject ID
  - volunteers using multiple identities

Issues in Performance Tests

Scientific approach

- Separation of training/development data versus test data
- Avoid to use artificially generated data (synthetic data)
- Size of data base must be sufficient
  for the claimed error rates
  - rule of 3

Test Size versus Uncertainty

Rule of 3

- The Rule of 3 addresses the question
  "*What is the lowest error rate that can be statistically established with a given number N of independent identically distributed comparisons?*"
- This value is the error rate *p* for which the probability of zero errors in *N* trials, purely by chance, is (for example) 5%.
- This gives:

$$p \approx \frac{3}{N}$$

for a 95% confidence level

Fundamental Metrics
in Technology Testing

Basic Metrics

Comparison scores

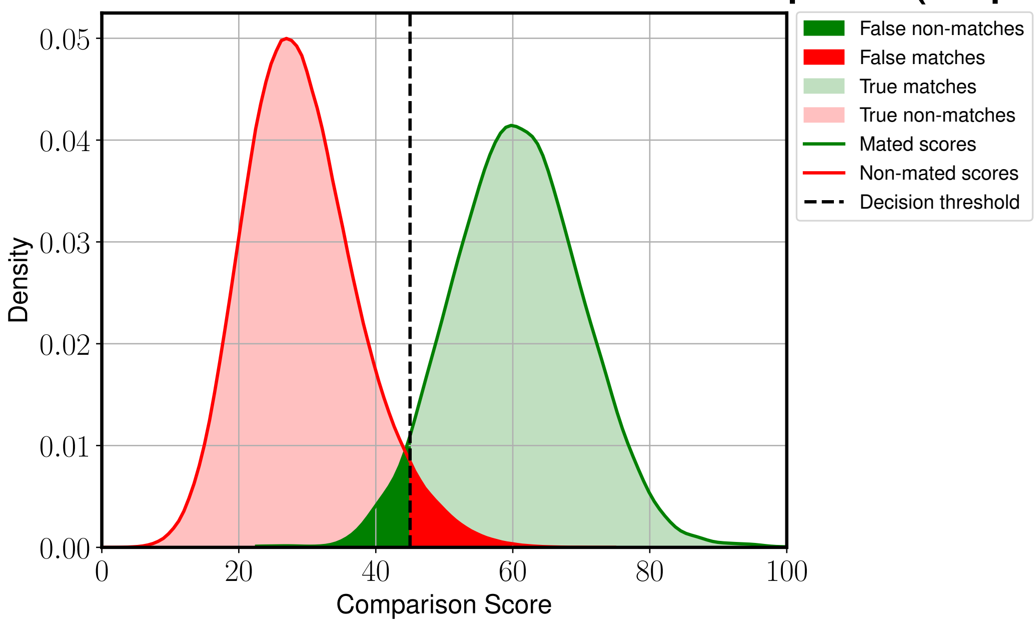
- **comparison score** $c(Q,R)$**:**
  - *numerical value (or set of values) resulting from a comparison*
    NOTE: the term ~~„matching score“~~ is deprecated by ISO
- **similarity score** $s(Q,R)$ **:**
  - *comparison score that increases with similarity*
- **distance score / dissimilarity score** $d(Q,R)$**:**
  - *comparison score that decreases with similarity*
  - Some distance measure
  - Often $d(Q,R) \geq 0$ and $d(R,R) = 0$
- Conversion
  - $s = f(d)$ where f is a monotonically decreasing function
  - Examples

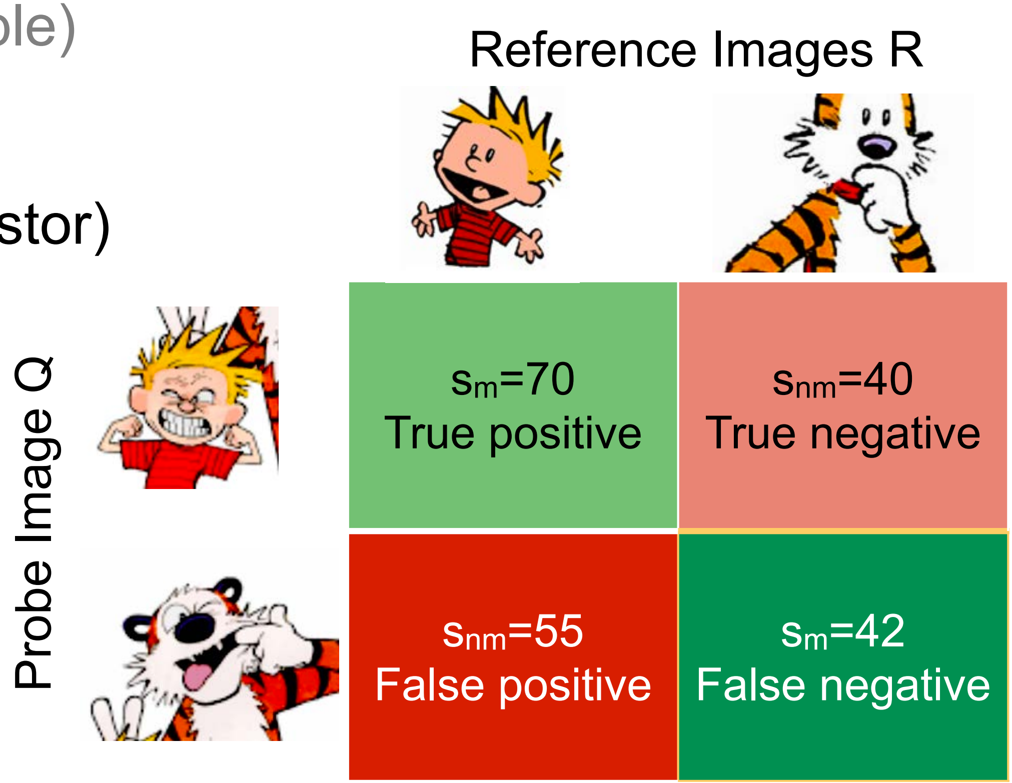
$$s = -d \qquad s = -log(d) \qquad s = \frac{1}{d}$$

Basic Metrics

Graphical representation of results

- Probability Density Function (PDF) for similarity scores $s(Q,R)$
  - t - threshold = 45 (in this example)
  - m - mated samples (genuine)
  - nm - non-mated samples (impostor)





Performance Metrics - Security

Probability density Distribution Function (PDF)

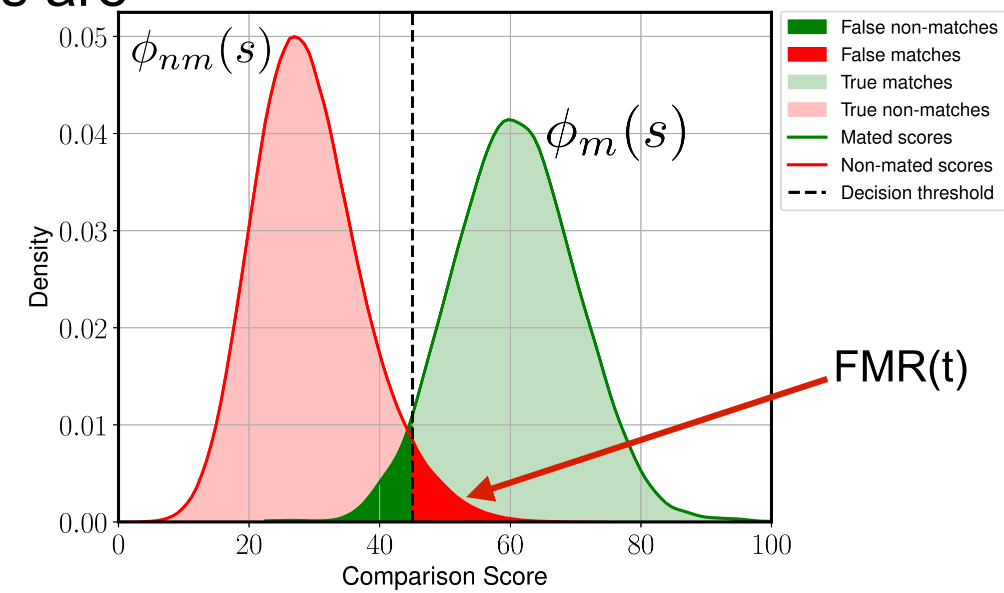
$\phi_m(s)$: PDF of mated similarity score $s(Q,R)$

$\phi_{nm}(s)$: PDF of non-mated similarity score $s(Q,R)$

False-Match-Rate (FMR)

- **Def in ISO-HBV:** *proportion of the completed biometric non-mated comparison trials that result in a false match*
- Note: non-mated comparison trials are also referred to as impostor trials
- False positive decision

$$FMR(t) = \int_t^1 \phi_{nm}(s)ds$$



Performance Metrics - Convenience

Probability density Distribution Function (PDF)

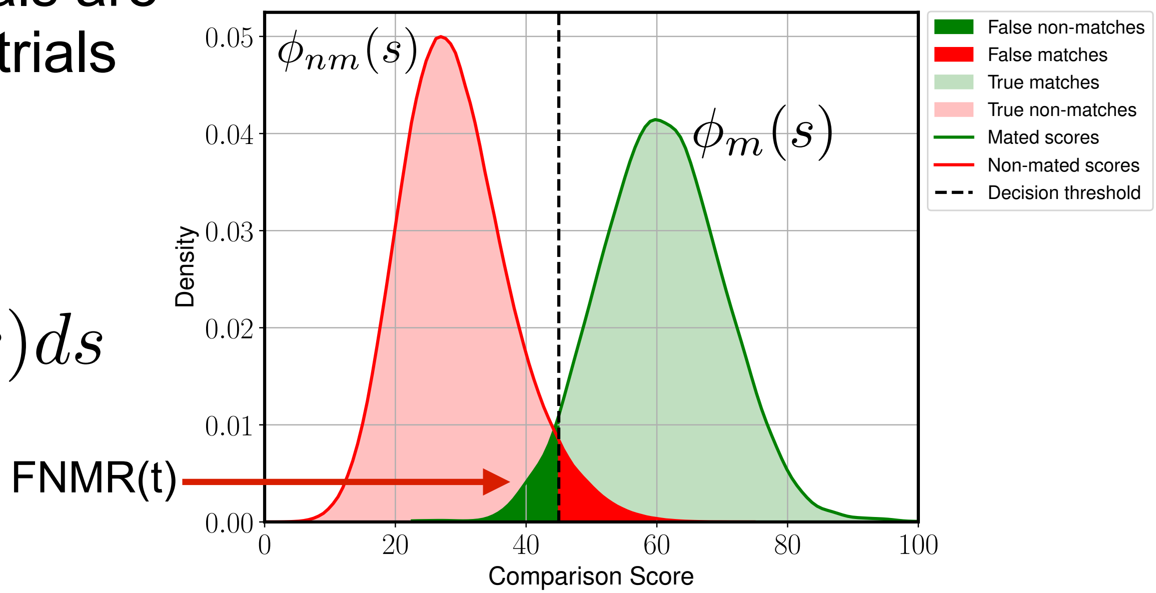
$\phi_m(s)$: PDF of mated similarity score $s(Q, R)$

$\phi_{nm}(s)$: PDF of non-mated similarity score $s(Q, R)$

False-Non-Match-Rate (FNMR)

- **Def in ISO-HBV:** *proportion of the completed biometric mated comparison trials that result in a false non-match*
- Note: mated comparison trials are also referred to as genuine trials
- False negative decision

$$FNMR(t) = \int_0^t \phi_m(s)ds$$



Performance Metrics - Different View

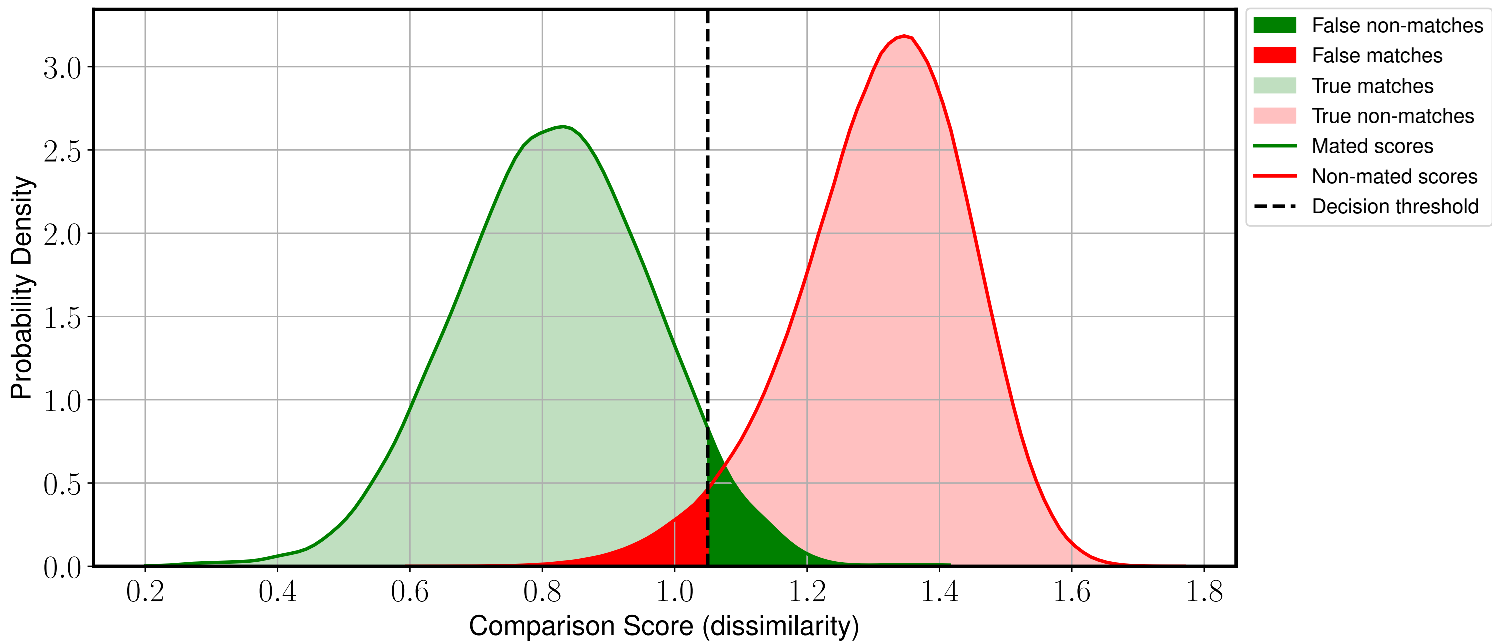
Probability density Distribution Function (PDF)

$\phi_m(d)$: PDF of mated dissimilarity score $d(Q,R)$

$\phi_{nm}(d)$: PDF of non-mated dissimilarity score $d(Q,R)$

$$FMR(t) = \int_0^t \phi_{nm}(d)dd$$

$$FNMR(t) = \int_t^{max_d} \phi_m(d)dd$$



Performance Metrics

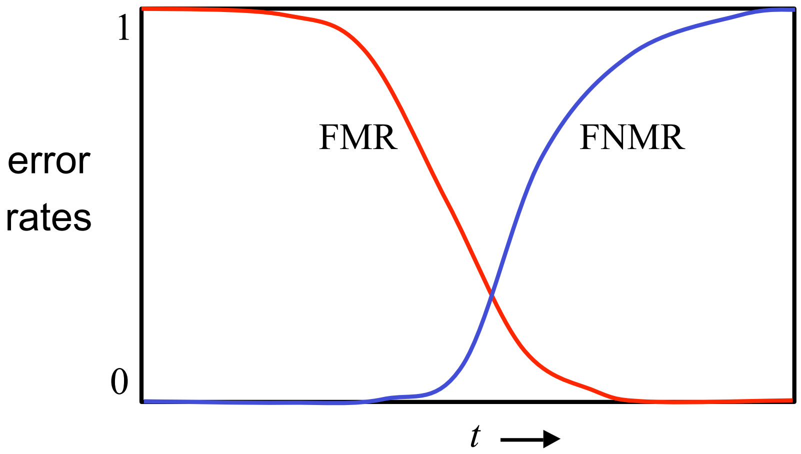
Algorithm error rates

- False-Match-Rate (FMR) - often confused with FAR
- False-Non-Match-Rate (FNMR) - often confused with FRR

Single number

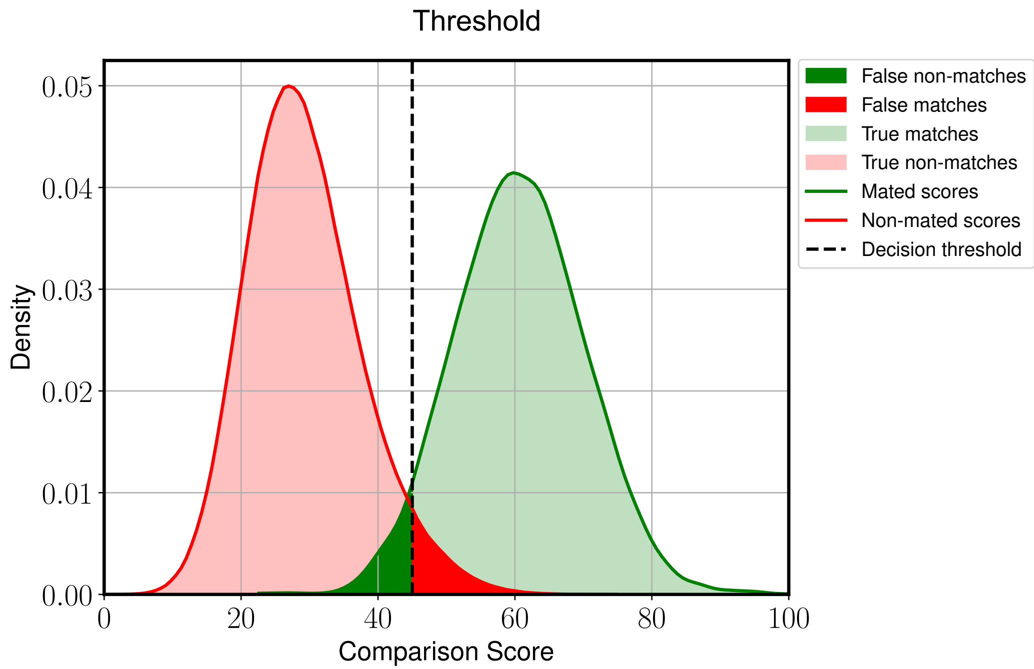
- Equal-Error-Rate (EER)

Constraints:



$$FMR(0) = 1, FMR(1) = 0$$

$$FNMR(0) = 0, FNMR(1) = 1$$



More Metrics

Verification rates

- Genuine-Match-Rate (GMR)
  - true positives

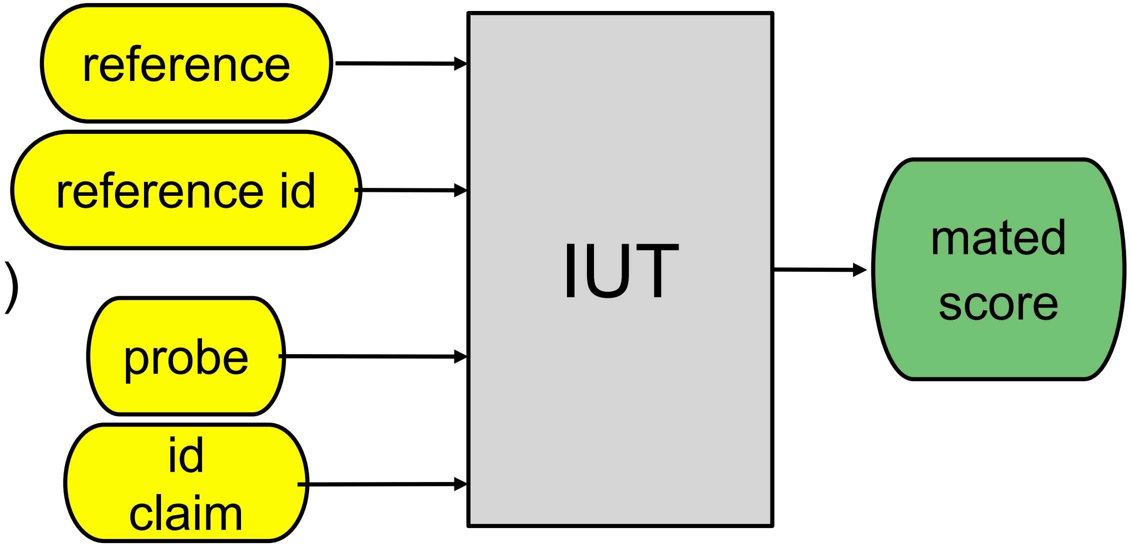
    $GMR = 1 - FNMR$

  - false negatives

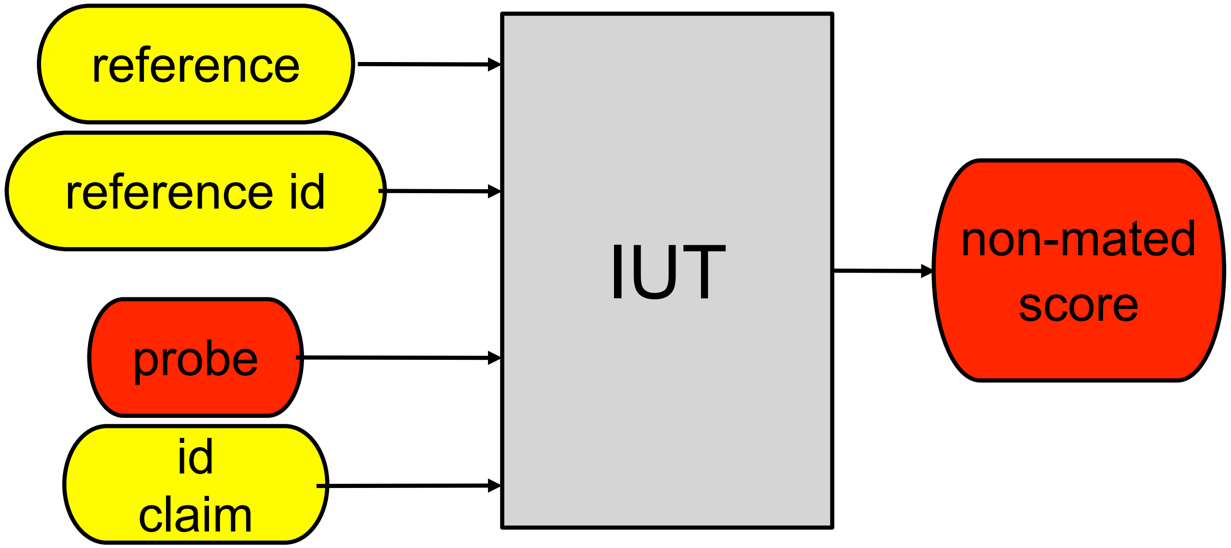
    $FNMR = 1 - GMR$

Performance Evaluation

Mated
comparison trial
(taken from the
same biometric instance)



Non-mated
comparison trial
(taken NOT from the
same instance)



References and probes are taken from a labeled test set

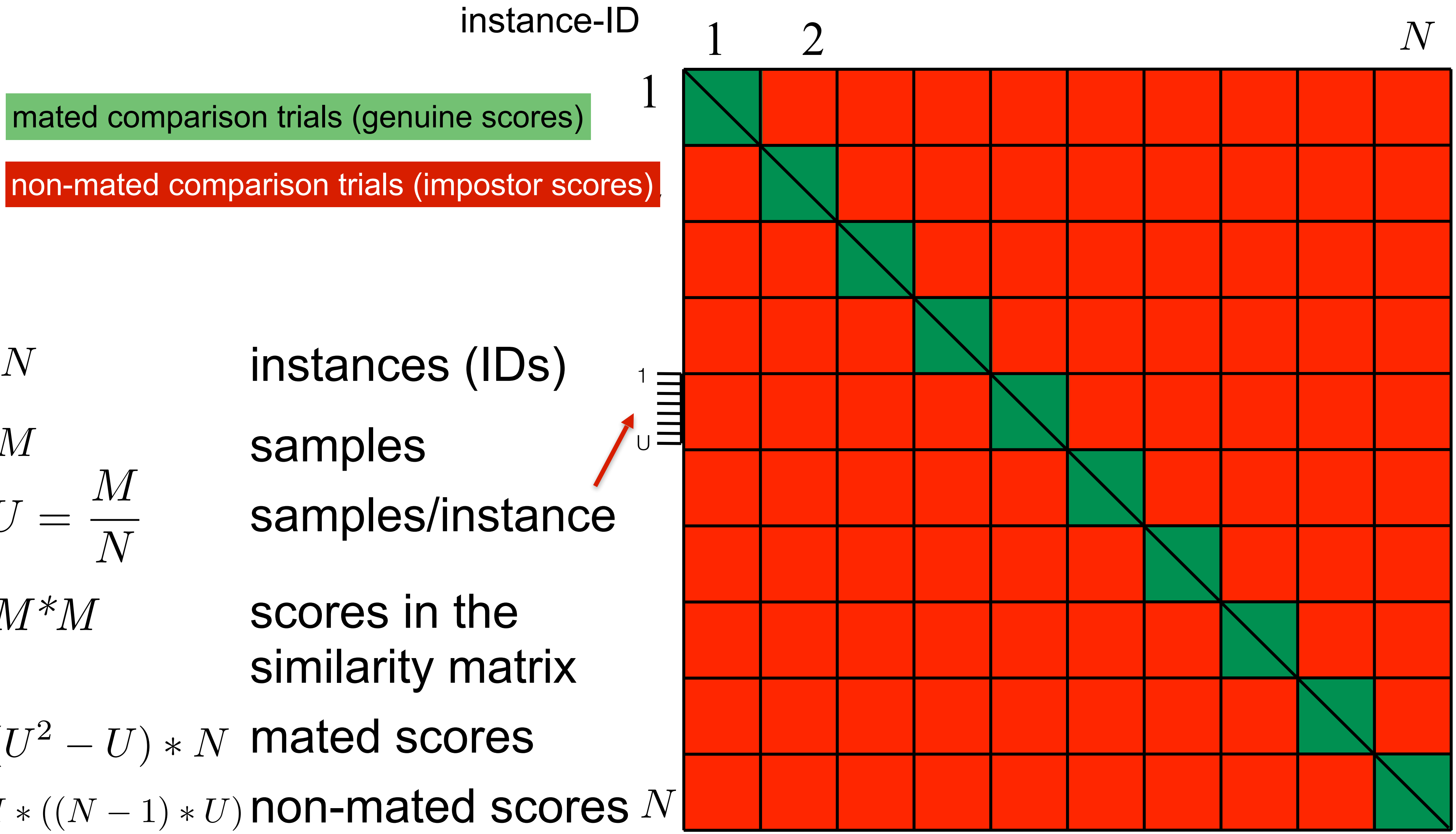
Similarity Matrix (closed set)

Similarity scores for a comparator

- 3 subjects (3 instances) captured in 2 sessions
  - 3 mated comparison scores
  - (3-1) * 3 non-mated comparison scores

probe samples \ enrolment samples	$face_1$	$face_2$	$face_3$
$face_1$	0.98	0.59	0.36
$face_2$	0.71	0.65	0.43
$face_3$	0.23	0.69	0.72

Similarity Matrix (closed set)



N	instances (IDs)
M	samples
$U = \frac{M}{N}$	samples/instance
$M*M$	scores in the similarity matrix
$(U^2 - U) * N$	mated scores
$M * ((N-1) * U)$	non-mated scores

Computation of FMR, FNMR and GMR

Computing algorithm error on a given corpus

Ω_m	set of all mated comparison scores (genuine)
Ω_{nm}	set of all non-mated comparison scores (impostor)
$\Omega_m(t)$	set of all mated scores $s > t$
$\Omega_{nm}(t)$	set of all non-mated scores $s > t$
$\lvert\Omega\rvert$	number of elements

$$FMR(t) = \frac{|\Omega_{nm}(t)|}{|\Omega_{nm}|}$$

$$GMR(t) = \frac{|\Omega_m(t)|}{|\Omega_m|}$$

$$\mathrm{FNMR}(t) = 1 - \mathrm{GMR}(t)$$

Computing FNMR and FMR

From similarity scores to algorithm errors

- for a defined threshold t = **0.66**
- False-Match-Rate ?
- Genuine-Match-Rate ?
- False-Non-Match-Rate?

	$face_1$	$face_2$	$face_3$
$face_1$	0.98	0.59	0.36
$face_2$	0.71	0.65	0.43
$face_3$	0.23	0.69	0.72

Computing FNMR and FMR

From similarity scores to algorithm errors

- for a defined threshold t = **0.73**
- False-Match-Rate ?

- Genuine-Match-Rate ?

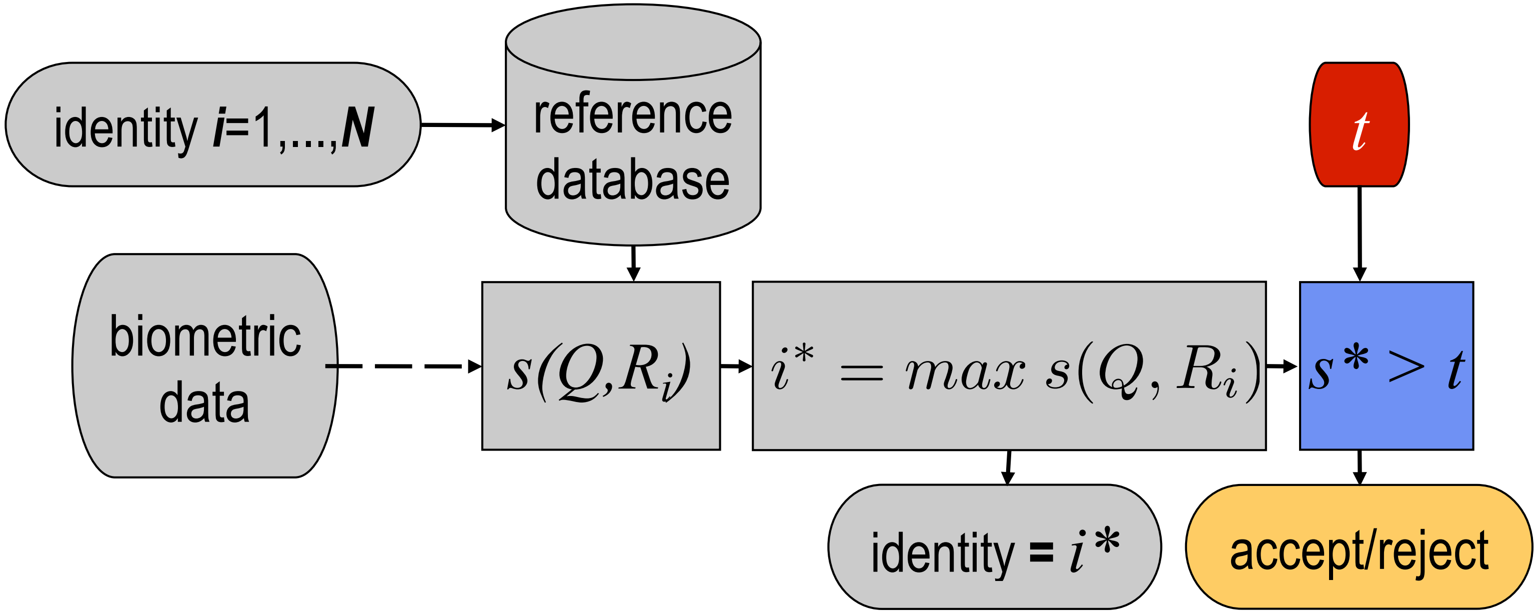
- False-Non-Match-Rate?

	$face_1$	$face_2$	$face_3$
$face_1$	0.98	0.59	0.36
$face_2$	0.71	0.65	0.43
$face_3$	0.23	0.69	0.72

Open Set Identification Error Rates

Confusion: (non-enrolled) subject i is identified as subject j

- False positives – there is always a closest enrolled subject !
- Countermeasure: include threshold.



False Positive Identification Rate (FPIR):

proportion of identification transactions by capture subjects not enrolled in the system for which a reference identifier is returned

Open Set Identification Error Rates

False-Positive-Identification-Rate (FPIR)

$$FPIR = (1 - FTAR) * (1 - (1 - FMR)^N)$$

- for small *FMR* we can substitute

$$(1 - FMR)^N \approx 1 - N * FMR$$

- and thus the *FPIR* can be approximated with

$$FPIR = (1 - 0) * (1 - (1 - N * FMR))$$

$$FPIR = N * FMR$$

Take care, when implementing identification systems,
as the error will increase about linearly with the size *N* !

Overview Metrics

From algorithm testing to system level testing

- Consider different types of test
  - Technology testing
    - offline evaluation of one or more algorithms
  - Scenario testing
    - evaluation of simulated application
  - Operational testing
    - evaluation in which the performance of a complete biometric system is determined

Overview Metrics

From algorithm testing to system level testing

- Technology testing
  - Algorithmic level verification error
    - False-Match-Rate (FMR) - algorithm accepts „zero-effort“ impostor
    - False-Non-Match-Rate (FNMR) - algorithm rejects true identity
- Scenario testing and operational testing
  - System level verification error
    - False-Accept-Rate (FAR)
    - False-Reject-Rate (FRR)
- System level error requires observation of:
  - Sample generation: Failure-to-Capture-Rate (FTCR)
  - Enrolment: Failure-to-Enrol-Rate (FTER)
    no reference for this subject
  - Verification: Failure-to-Acquire-Rate (FTAR)
    no probe feature vector

System Error Metrics

False-Accept-Rate (FAR)

$$FAR = FMR * (1 - FTAR)$$

False-Reject-Rate (FRR)

$$FRR = FTAR + FNMR * (1 - FTAR)$$

System Error Metrics

Generalized False-Accept-Rate:

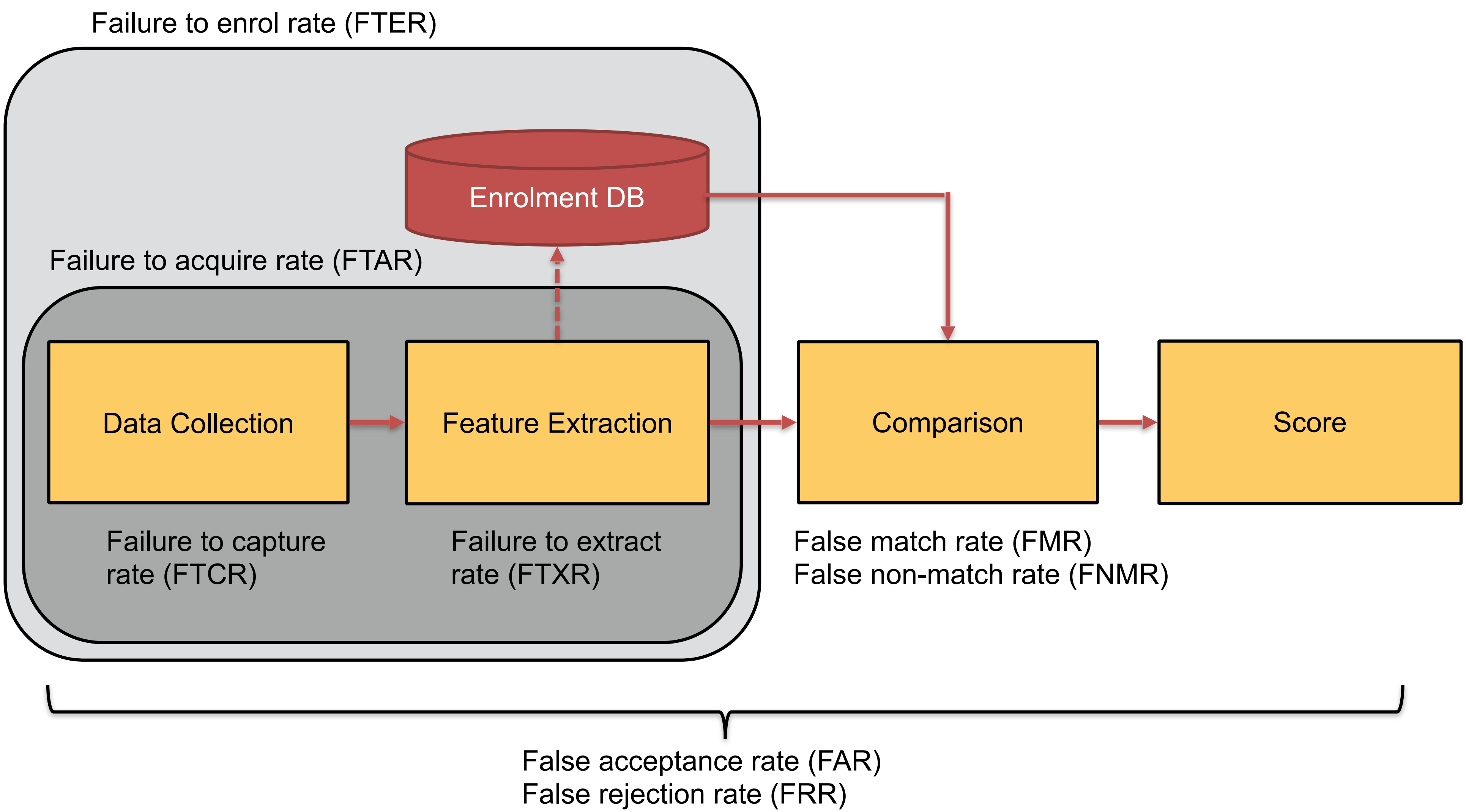
$$GFAR = FMR * (1 - FTAR) * (1 - FTER)$$

Generalized False-Reject-Rate:

$$GFRR = FTER + (1 - FTER) * FTAR + (1 - FTER) * (1 - FTAR) * FNMR$$

Summary of Performance Metrics

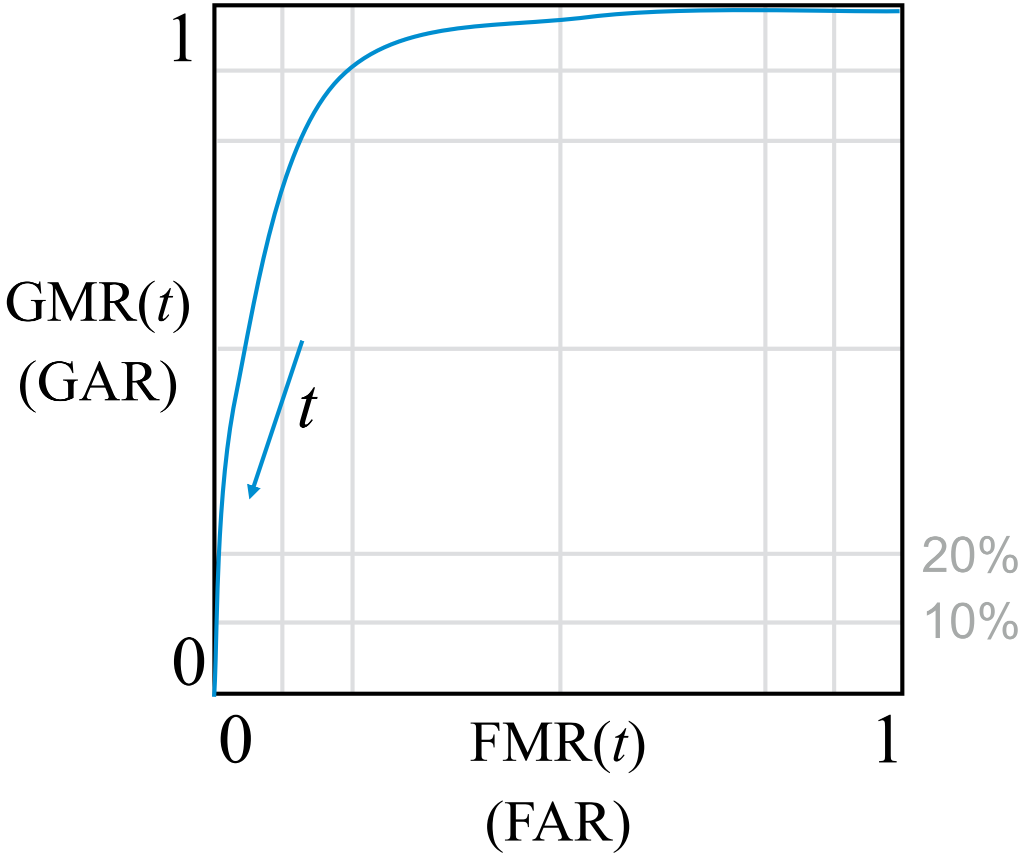
Potential failures in a biometric processing pipeline



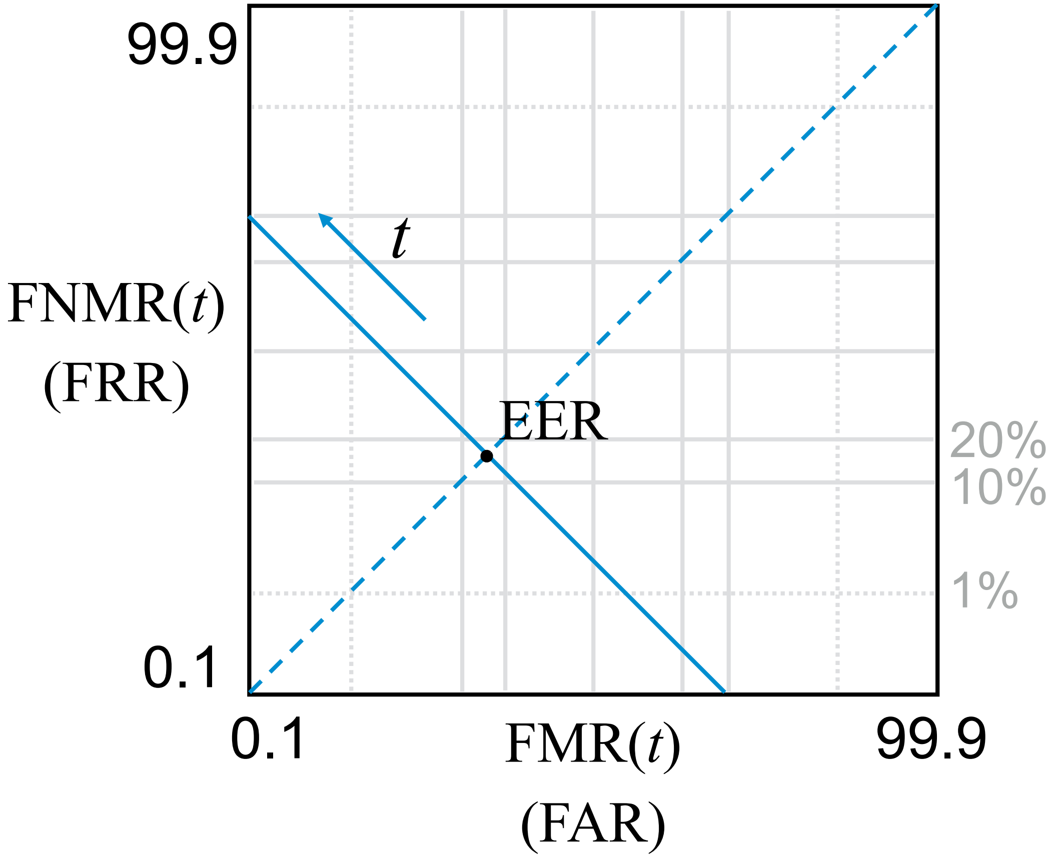
Reporting

Graphical Presentation

Receiver Operating Characteristic (ROC)



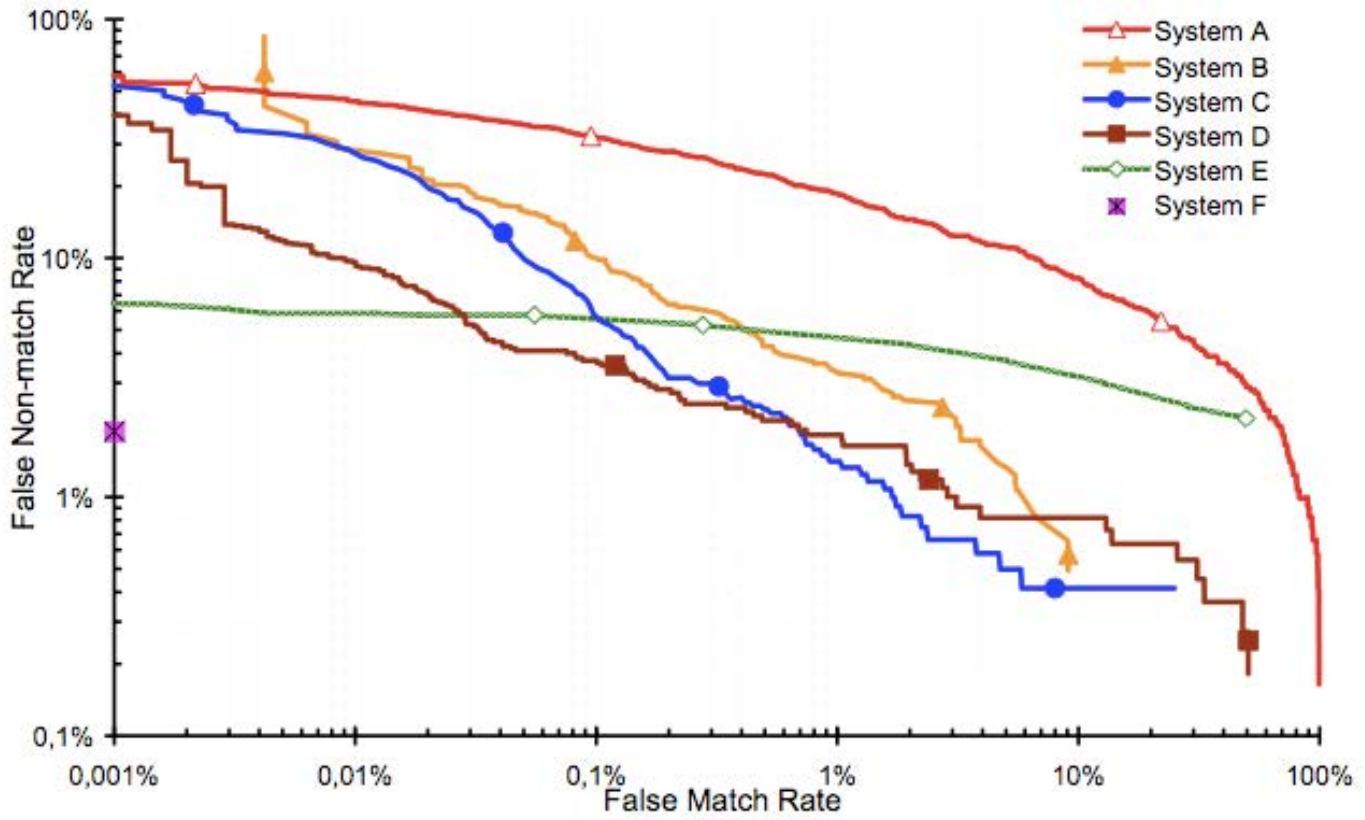
Detection Error Trade-off (DET) curve



Graphical Presentation

DET curve (detection error trade-off curve)

- Plots show error rates on both axes
  - false positives on the x-axis
  - false negatives on the y-axis

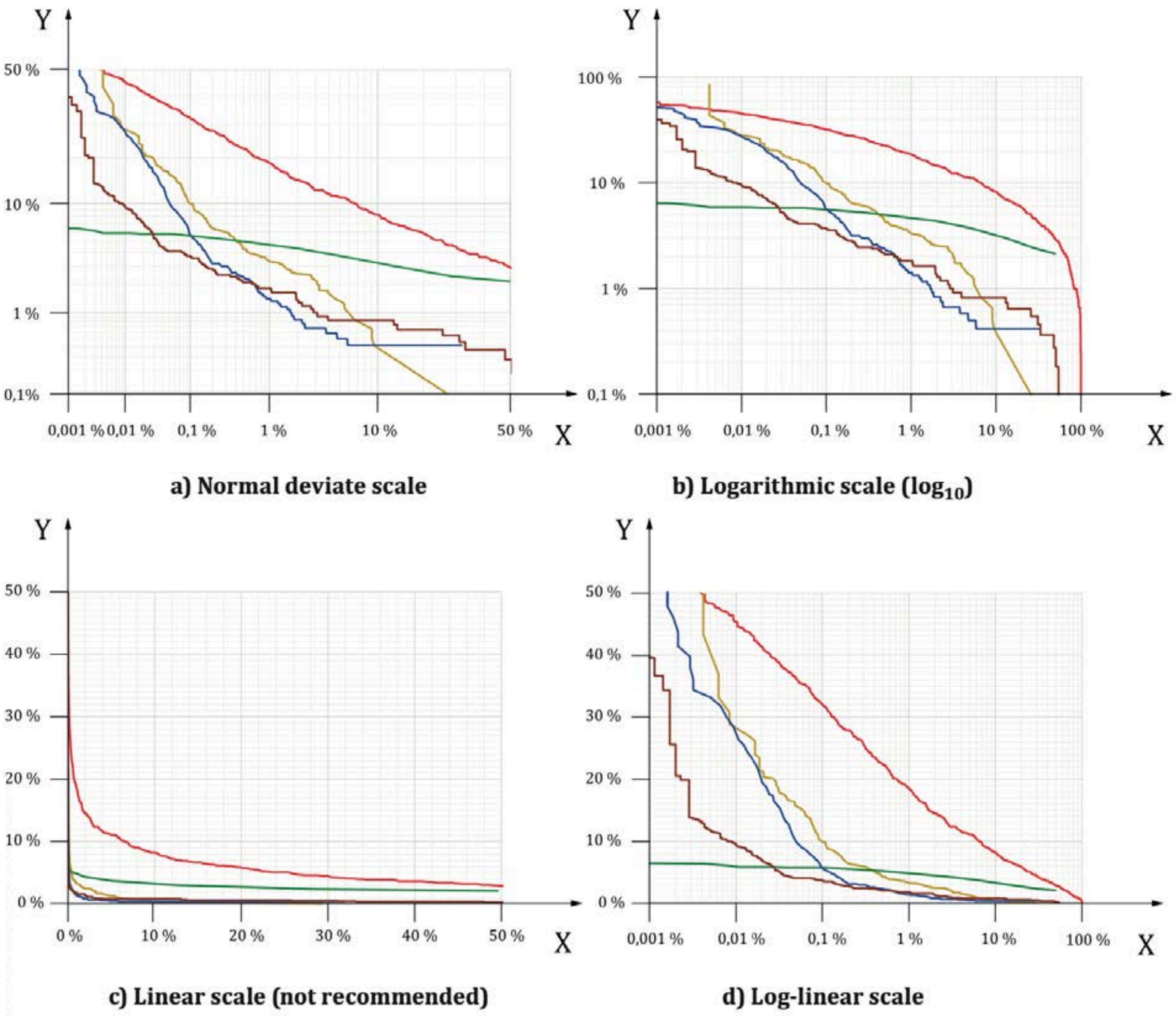


Source: ISO/IEC 19795-1:2006

Graphical Presentation

DET curve

- Plots are impacted by the scale

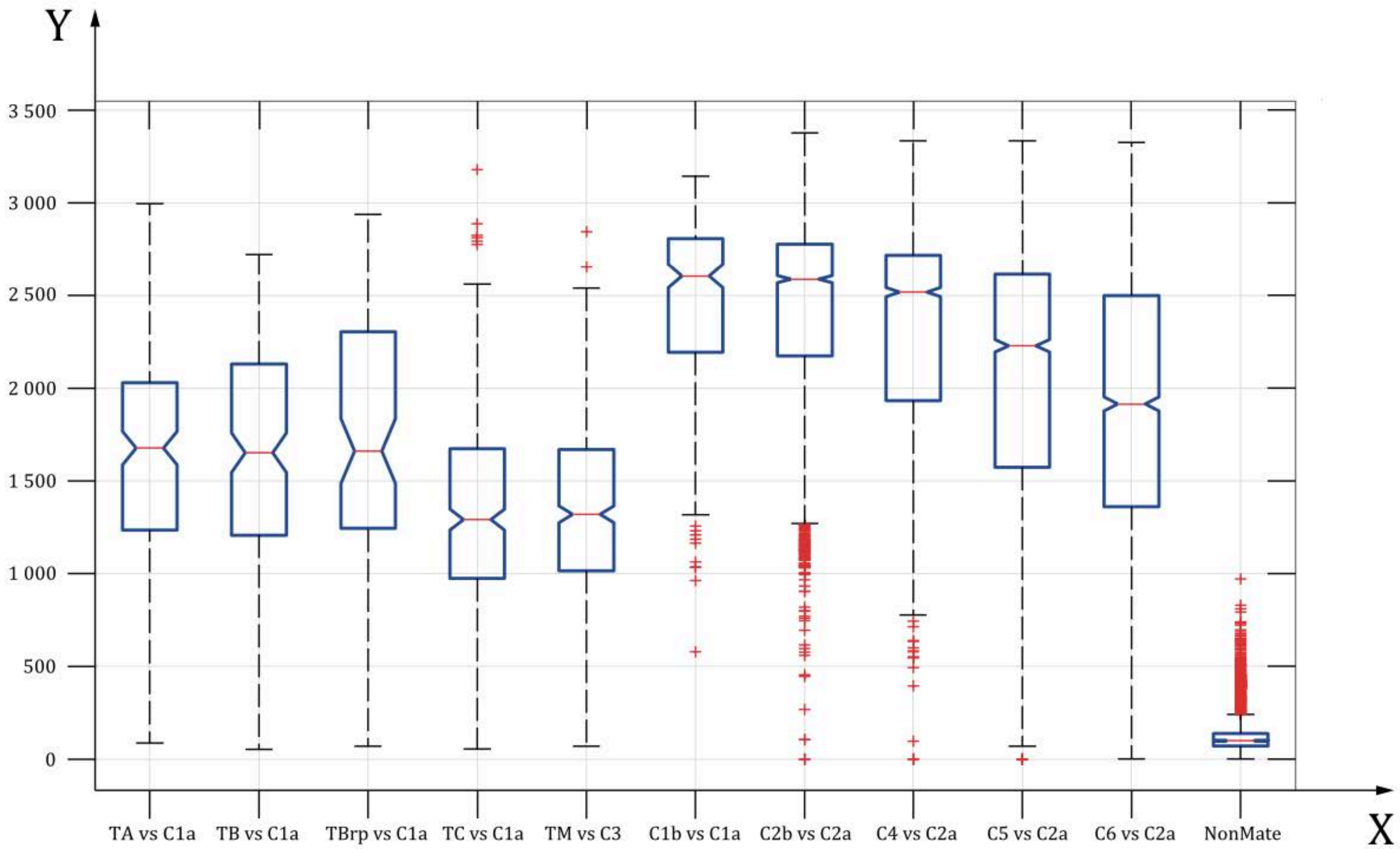


Source: ISO/IEC 19795-1:2021

Graphical Presentation

Visualising score distribution

- Boxplots and whisker plot
  - the boxes represent the interquartile range of each set of scores
  - the whisker extend from the box to the highest and lowest score

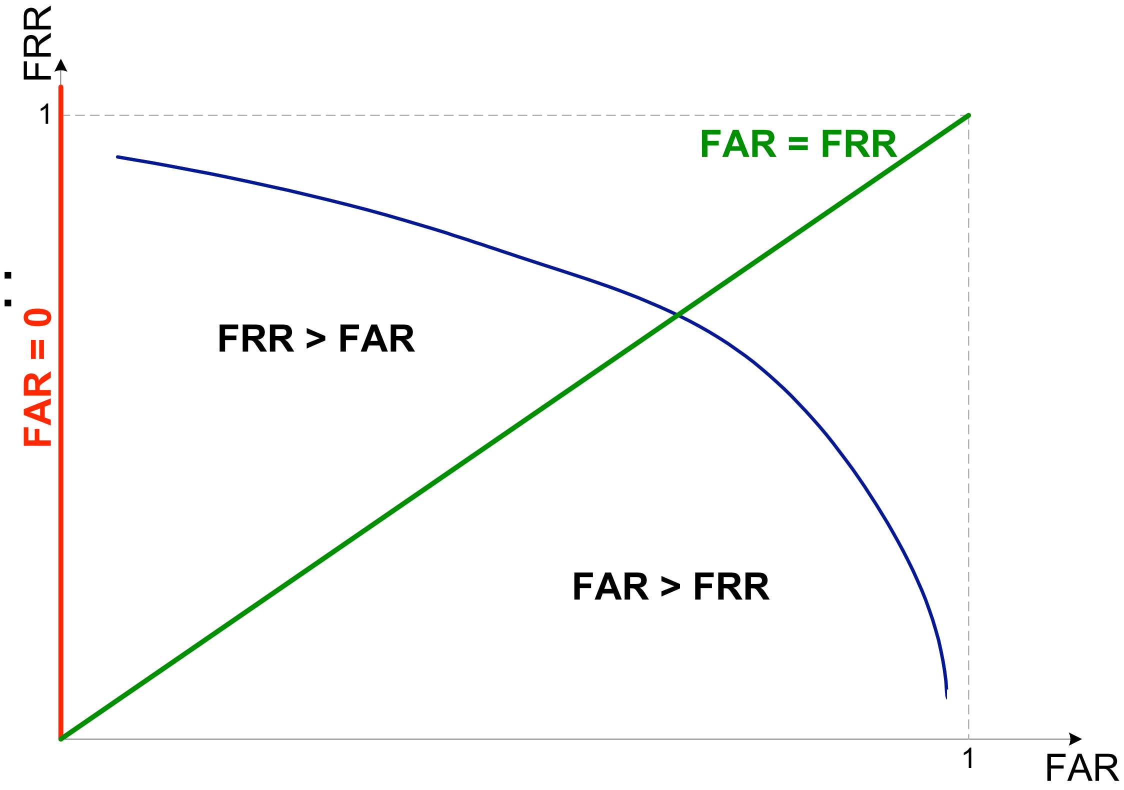


Source: ISO/IEC 19795-1:2021

Applications and DET

Applications and appropriate operational points

- Nuclear power plant:
  - FRR > FAR (FAR ≅ 0)
- Studio membership card:
  - FAR > FRR



Test Standards

Variations in Presentation of Results

5 US Government Tests

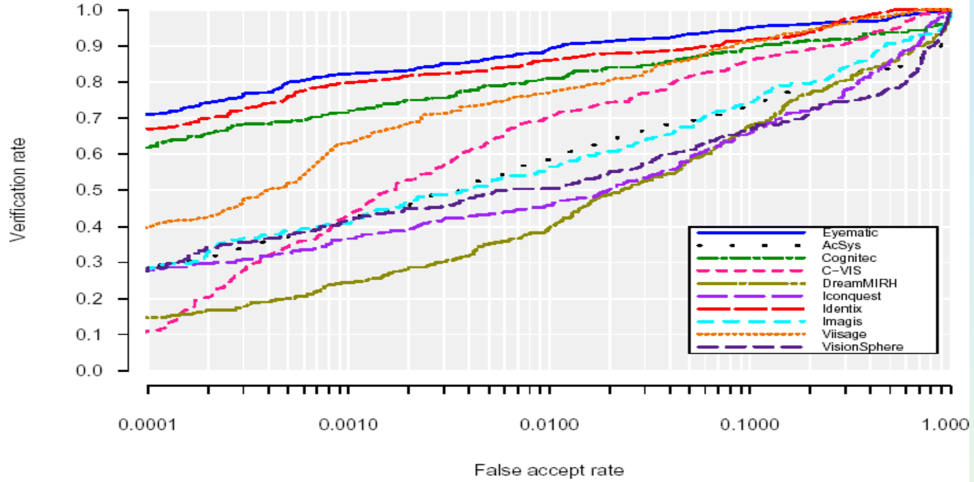
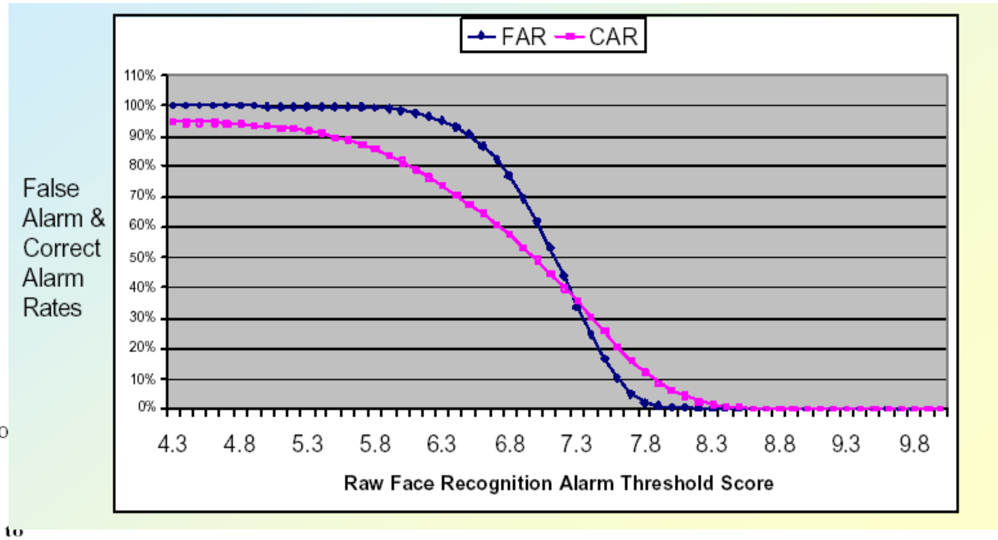
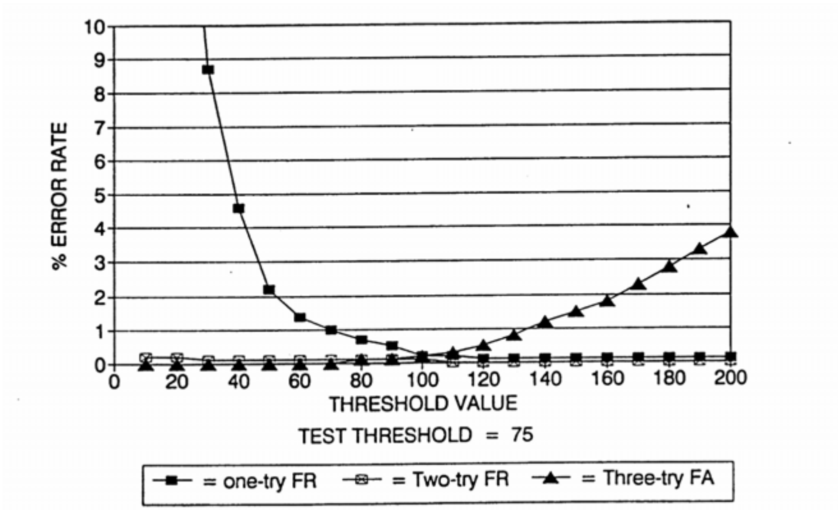
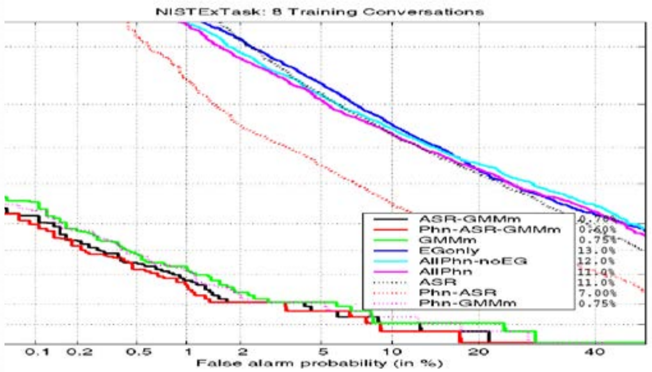
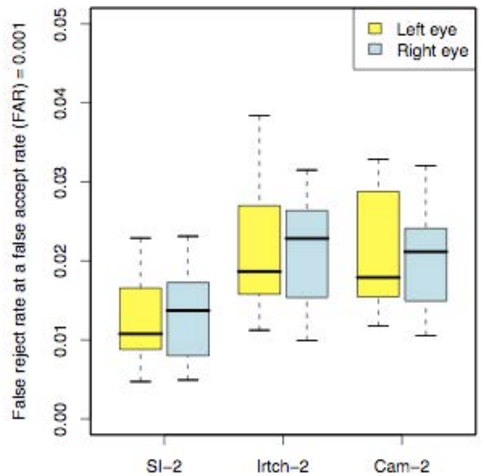


Figure L.18 - Verification Performance for Indoor (different day) Probes. This figure corresponds to Figure 22 in the *FRVT 2002: Evaluation Report.*









Biometric Performance Testing Standard

ISO/IEC 19795-x, Information technology -
Biometric performance testing and reporting

- Part 1: Principles & Framework (revised in 2021)
  - Guidance applicable to the broad range of tests
- Part 2: Testing Methodologies for Technology and Scenario Evaluation
- Part 3: Modality-Specific Testing
- Part 4: Interoperability Performance Testing
- Part 5: Framework for biometric device performance evaluation for access control
- Part 6: Testing methodologies for operational evaluation
- Part 7: Testing of on-card biometric comparison algorithms
- Part 9: Testing on mobile devices
- Part 10: Quantifying biometric system performance variation across demographic groups (under development)

Part 1: Principles & Framework

Content

- Definitions
  - describe biometric system
  - performance metrics
- Planning an evaluation
- Data collection
  - enrolment
  - one-to-one comparison trials
  - identification trials
- Analyses
- Graphical presentation of results
- Record keeping
- Reporting performance results

Required Metrics

Fundamental (always reported)

- Failure-to-Enrol Rate
- Failure-to-Acquire Rate
- False-Match-Rate vs. False-Non-Match-Rate

Verification

As above plus …

- False-Accept-Rate vs. False-Reject-Rate

And perhaps …

- Generalised error rates incl. enrolment failures
- Distribution of errors in test population …

Identification (open-set)

As above plus …

- False-Positive-Identification-Rate vs. False-Negative-Identification-Rate
  - (dependence on database size)

If binning used …

- Binning-Error-Rate
- Penetration-Rate
  - FMR & FNMR are within-bin error rates

Binning

Partitioning based on soft-biometrics

- skin and hair color

- eye color

- height

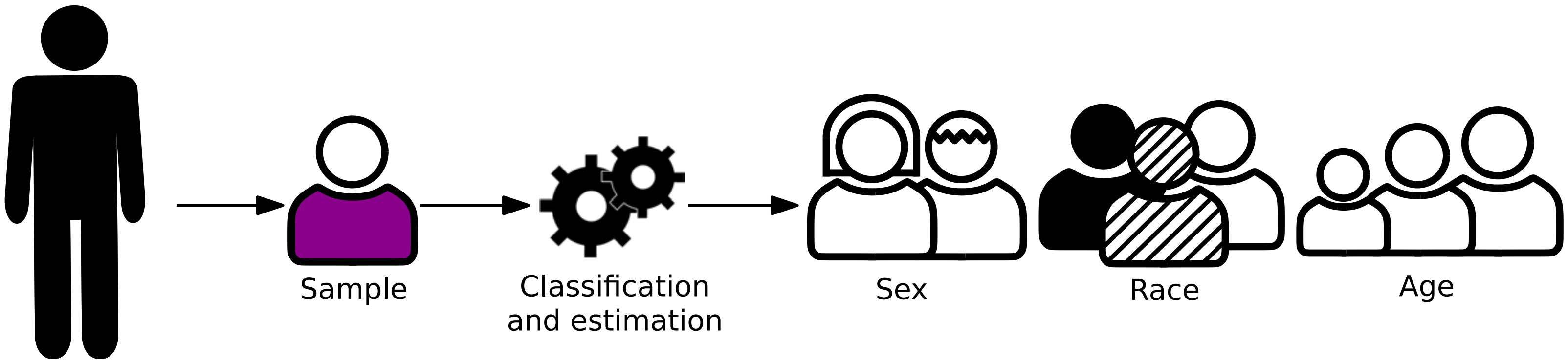
- weight

Image Source: A. Jain 2013

Binning

Partitioning based on soft-biometrics

- is done by classification algorithms that estimate membership in pre-defined soft-biometric classes

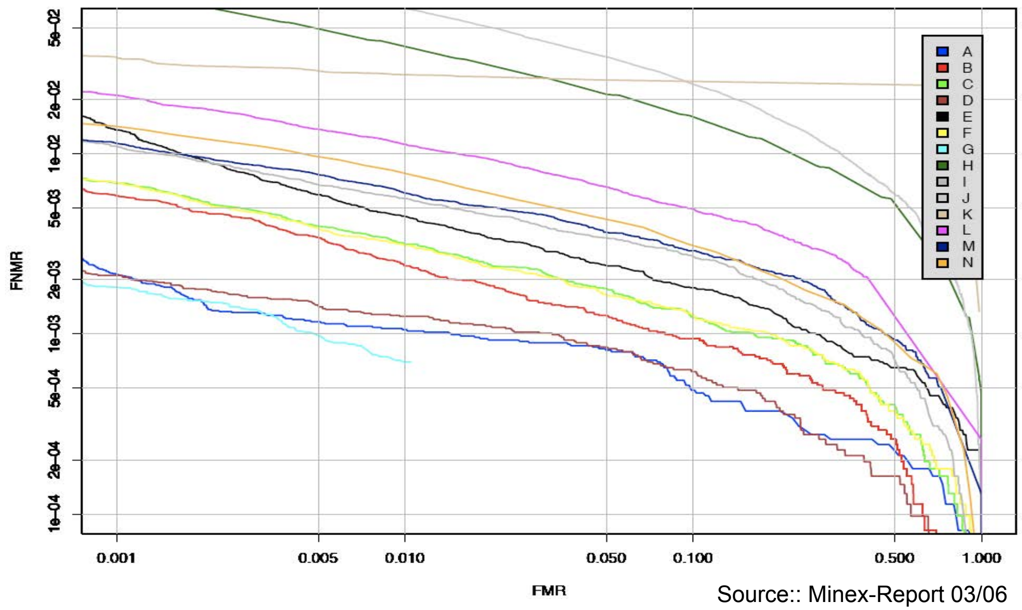


- Binning error / pre-selection error:
  error that occurs when the corresponding subject identifier is not in the preselected subset of candidates
- Penetration rate:
  average proportion of the total number of references that are pre-selected

Biometric Performance and Interoperability

Minutiae Interoperability Exchange Test - MINEX

- National Institute of Standards and Technology (NIST)
- Biometric Performance based on Images vs. Minutia-Templates
- Large test
  - Fingerprint images from 250.000 individuals
  - Live-Scan data
- DET-curves
  - False-Match-Rate
  - False-Non-Match-Rate
- Performance @ FMR 0,01
  - Image-1F: 0,0047
  - Minutia-1F: 0,0129
  - Image-2F: 0,0002



Source:: Minex-Report 03/06

References

A script computing DET curves will be provided

- This script shall be used for term paper reports
  on biometric performance or
  on presentation attack detection performance
- Python-code
- Matlab-code

References

Web

- National Institute for Standards and Technology
  http://fingerprint.nist.gov/
- BEAT testing platform
  https://www.beat-eu.org/news/the-beat-platform-goes-open-source

Complementary reading

- ISO/IEC 19795-1, “Biometric performance testing and reporting - Part 1: Principles and framework“, 2021
- B.D. Jovanovic, P. Levy, “A look at the rule of three”, The American Statistican, pp. 137-139, 1997
- G. R. Doddington, M. A. Przybocki, A.F. Martin and D.A. Reynolds, “The NIST speaker recognition evaluation: Overview methodology, systems, results, perspective”, Speech Communication, 2000